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Iyengar

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(54) **ABRASIVE ARTICLE INCLUDING SHAPED ABRASIVE PARTICLES**

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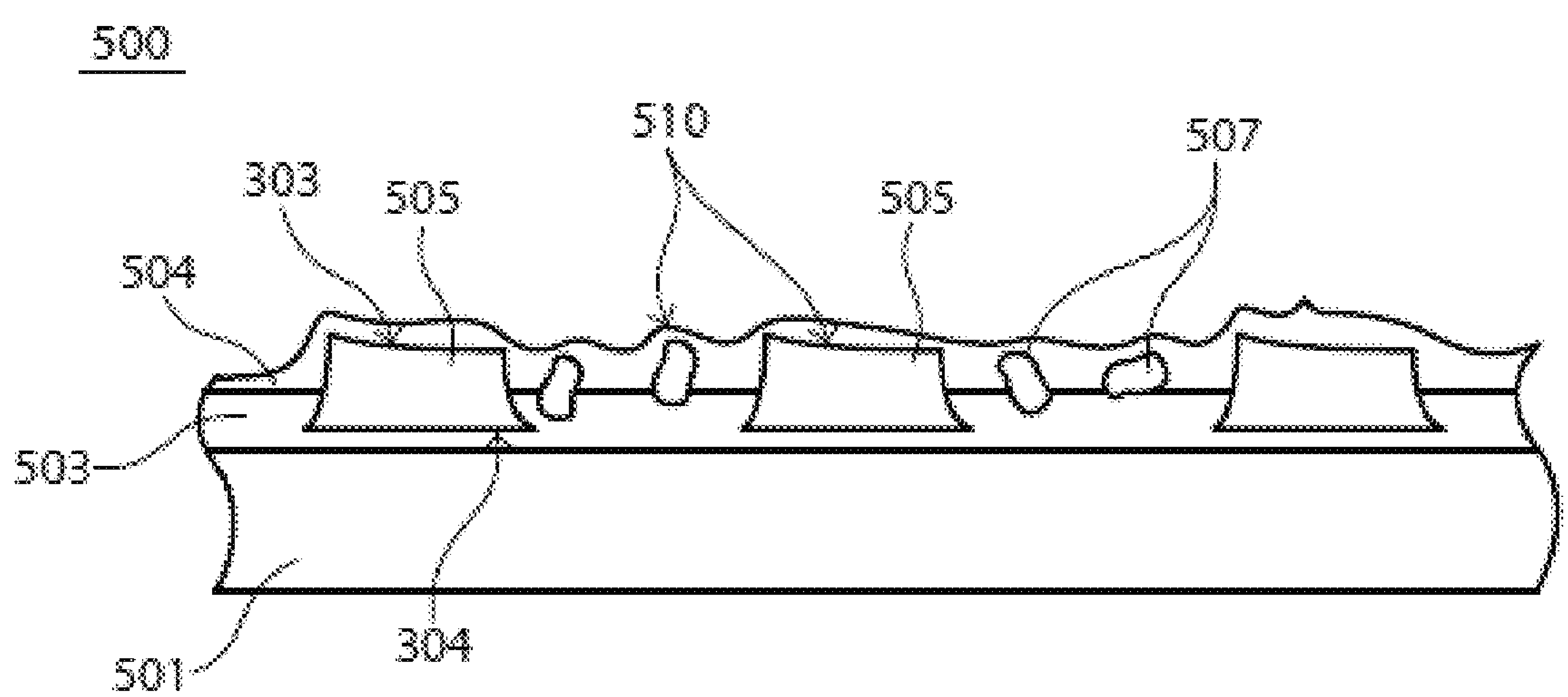
(57) **ABSTRACT**

A fixed abrasive article including a blend of abrasive particles having a first type of shaped abrasive particle comprising a first height (h**1**), a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height, where the blend of abrasive particles includes a first content of the first type of shaped abrasive particles and a second content of the second type of shaped abrasive particle, and the first content is different as compared to the second content.

19 Claims, 7 Drawing Sheets



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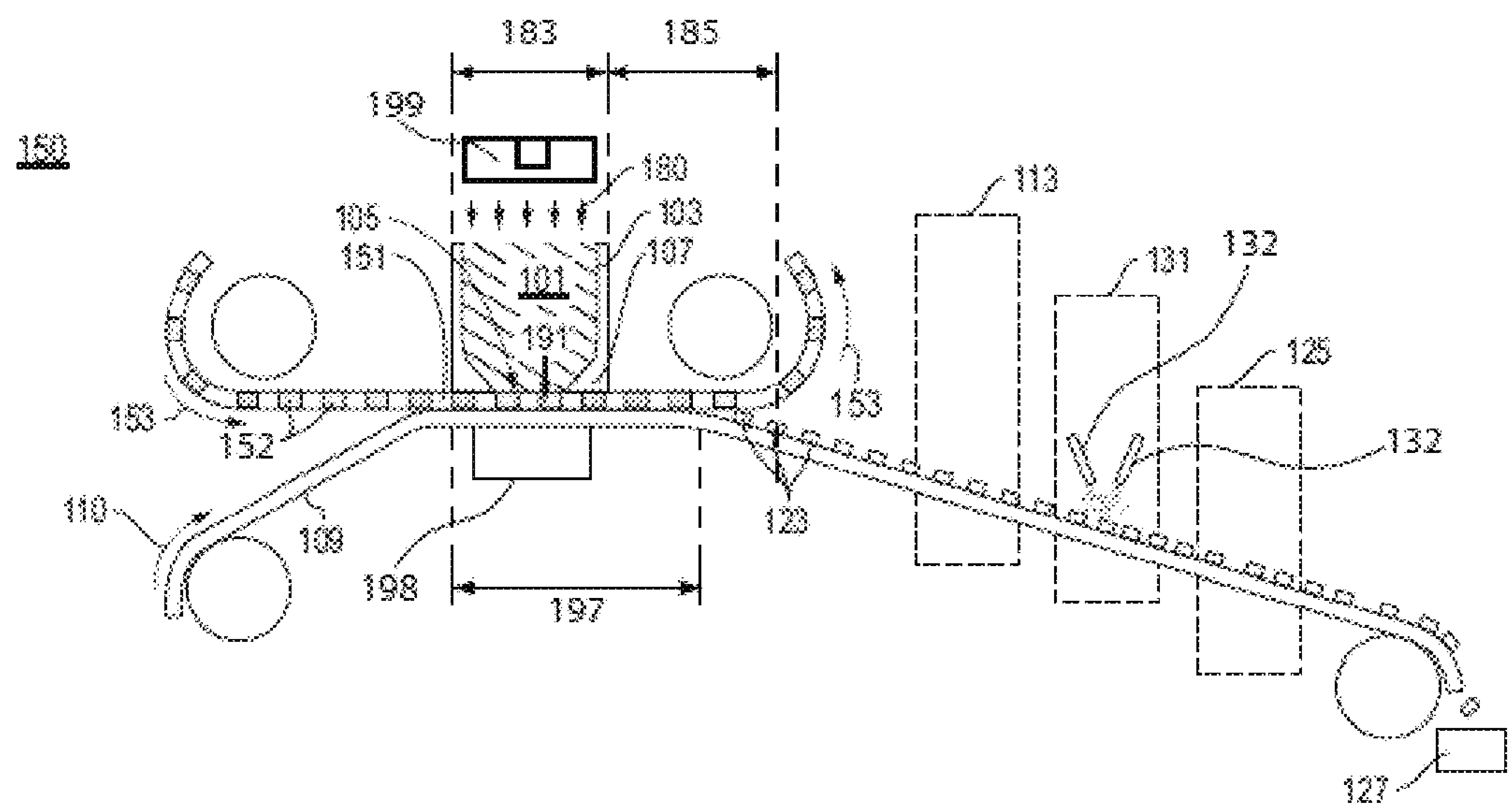
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185
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180
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153
132
110
109
123
198
197
127

FIG. 1A

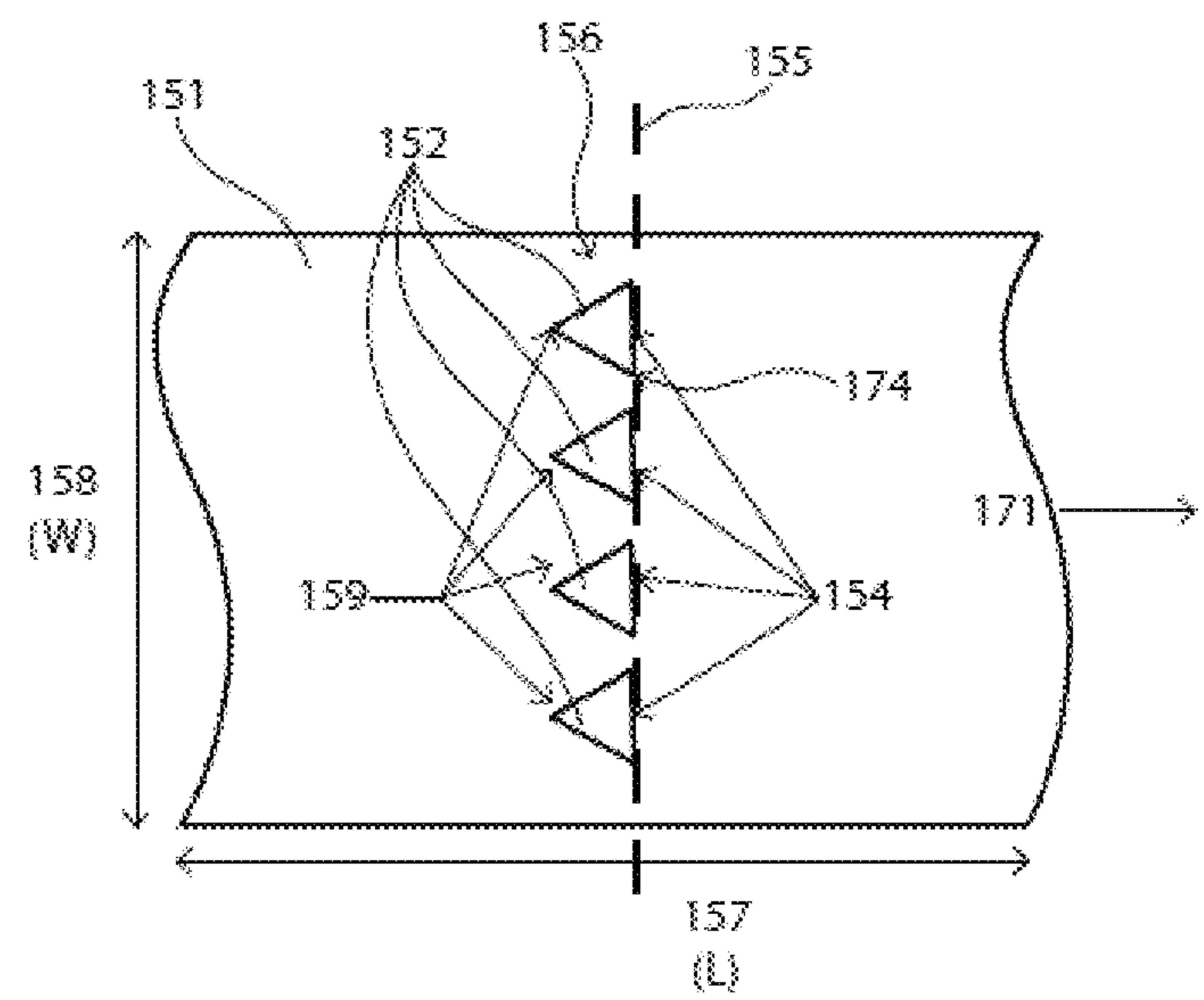
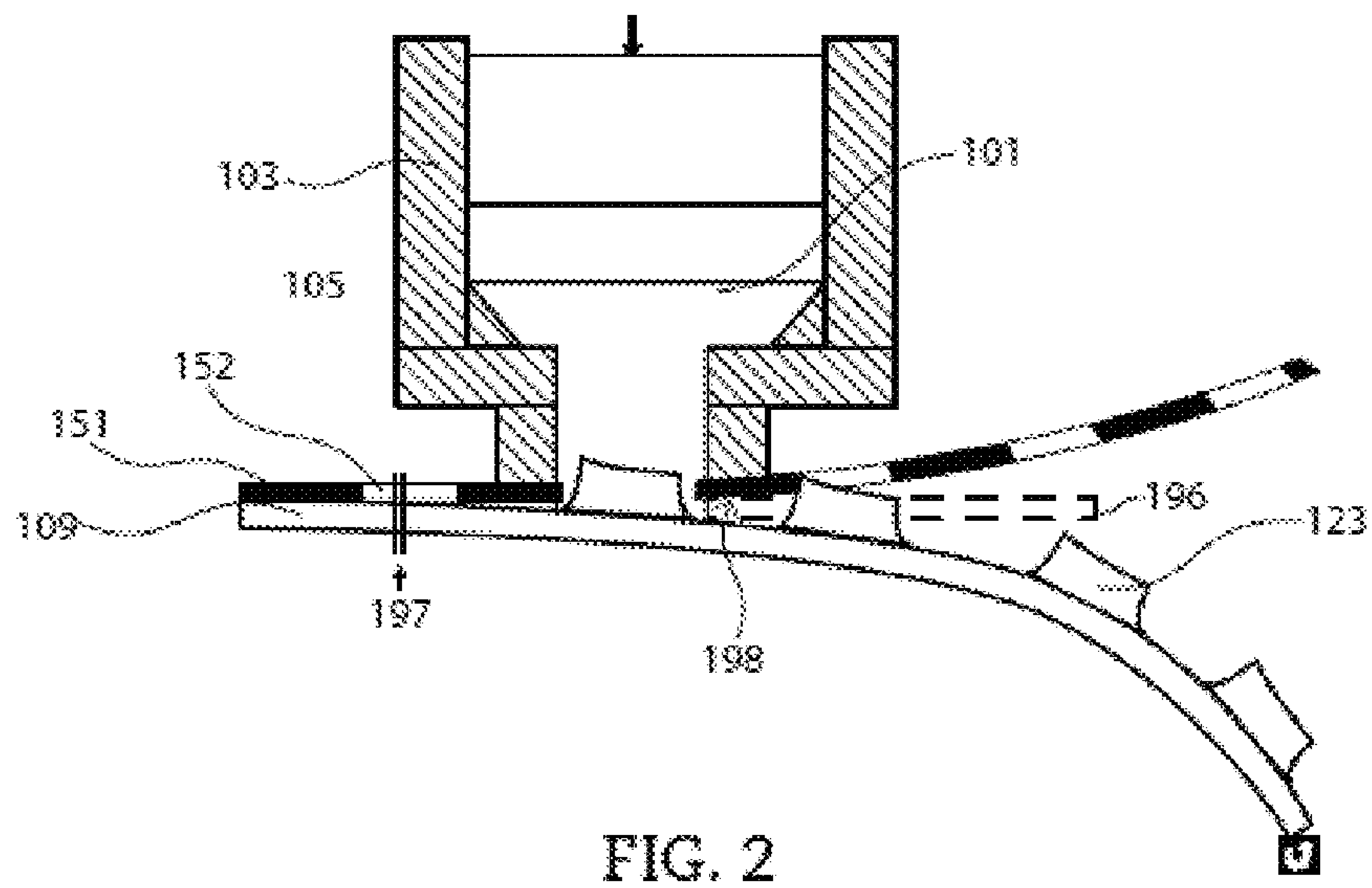

156
155
151
152
174
158
(W)
171
159
154
157
(L)

FIG. 1B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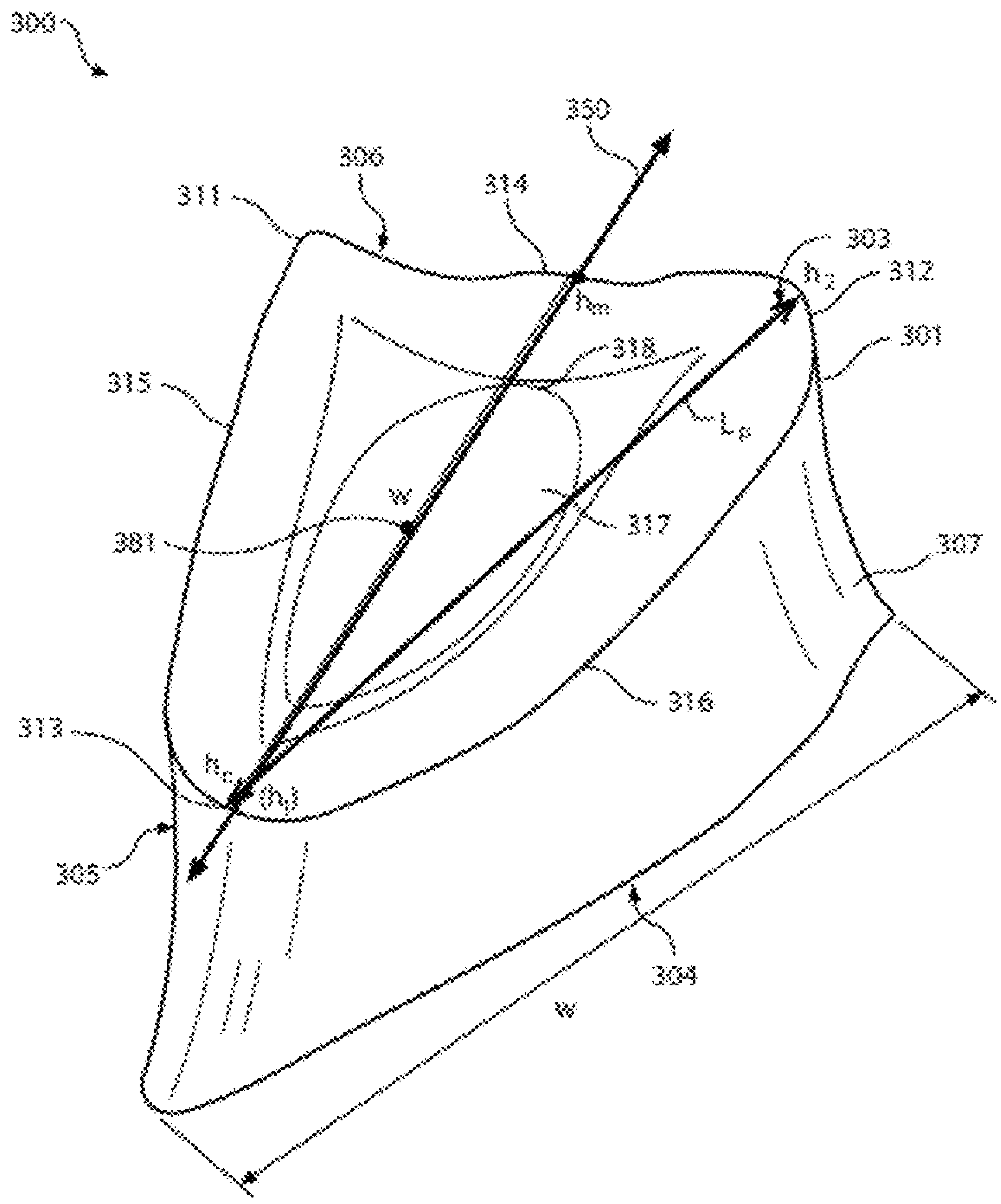
198

FIG. 2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381
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313
305
304
w

FIG. 3A

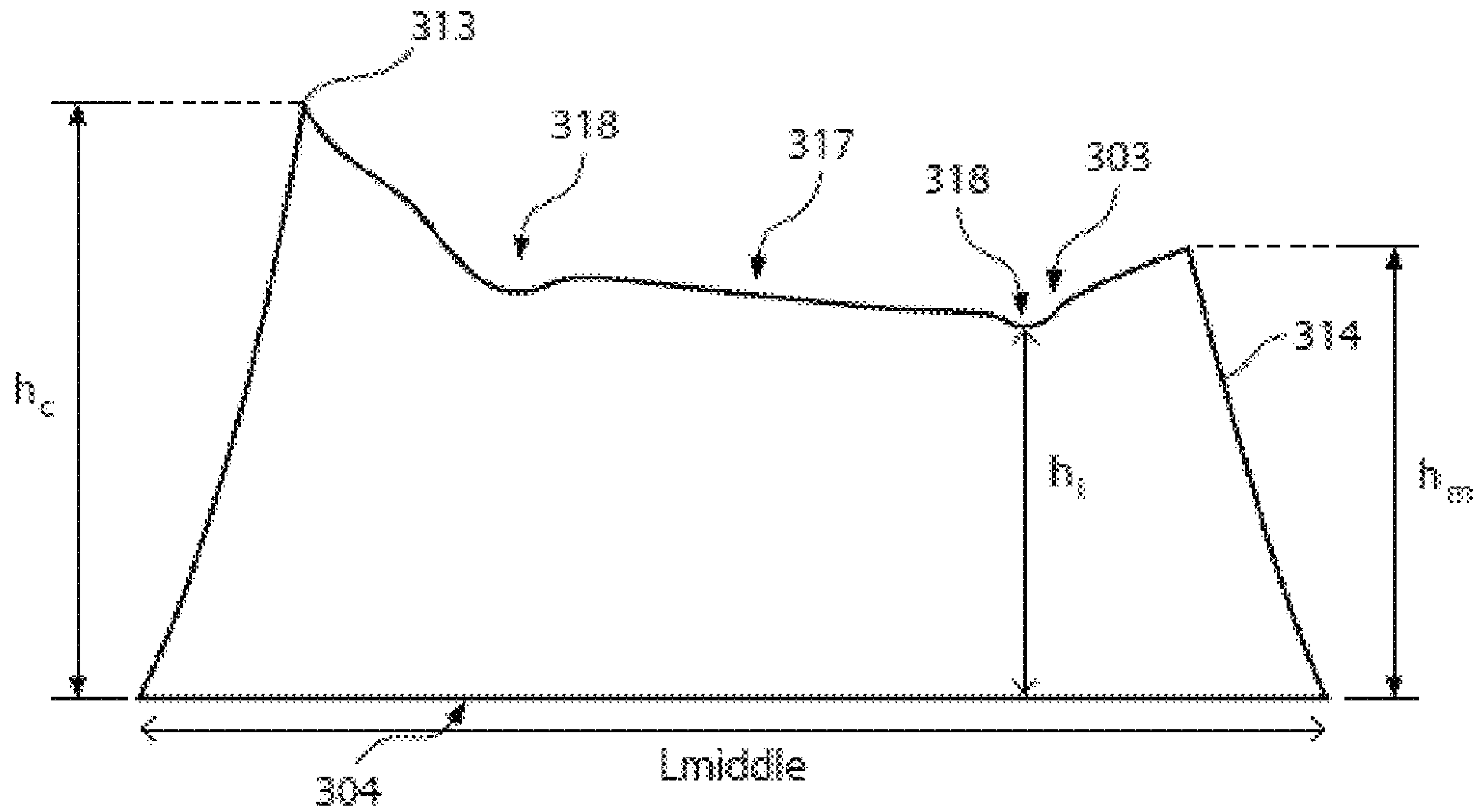


FIG. 3B

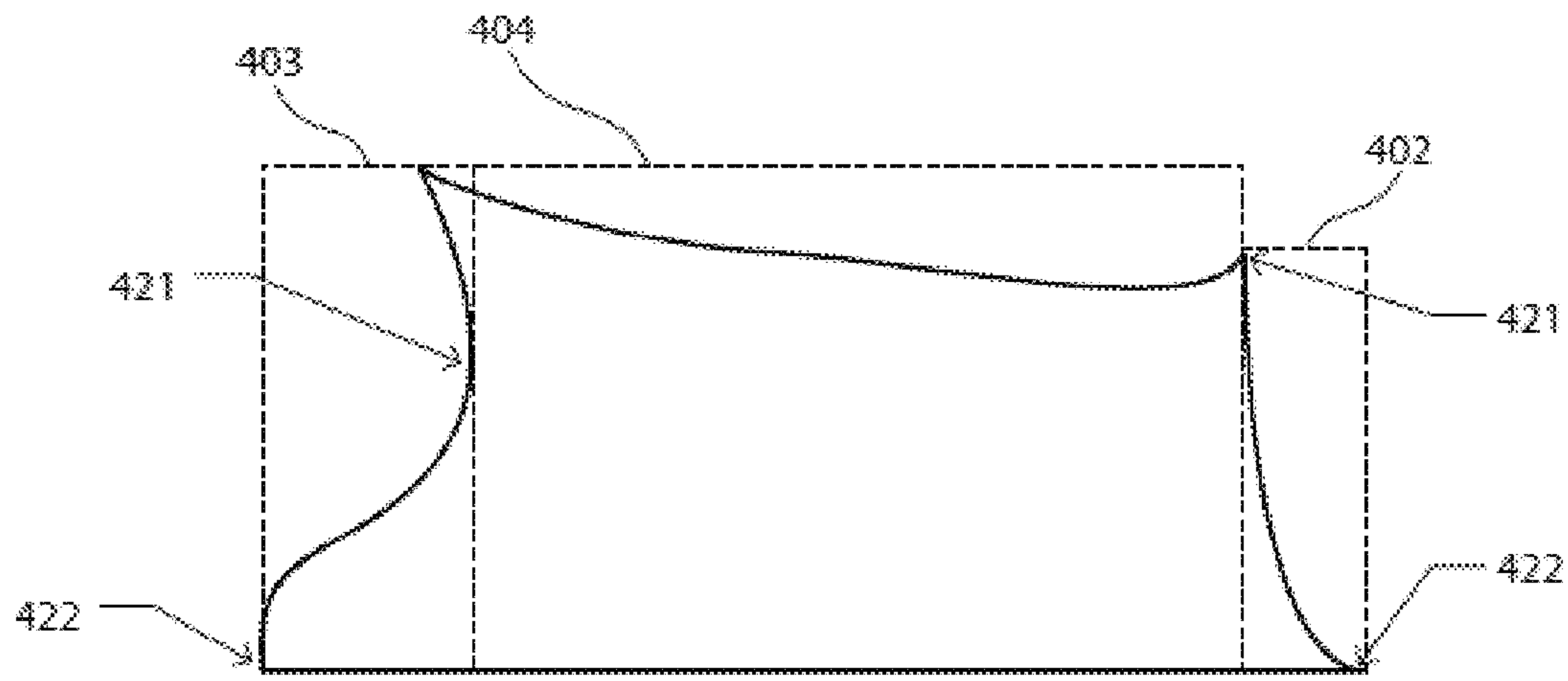


FIG. 4

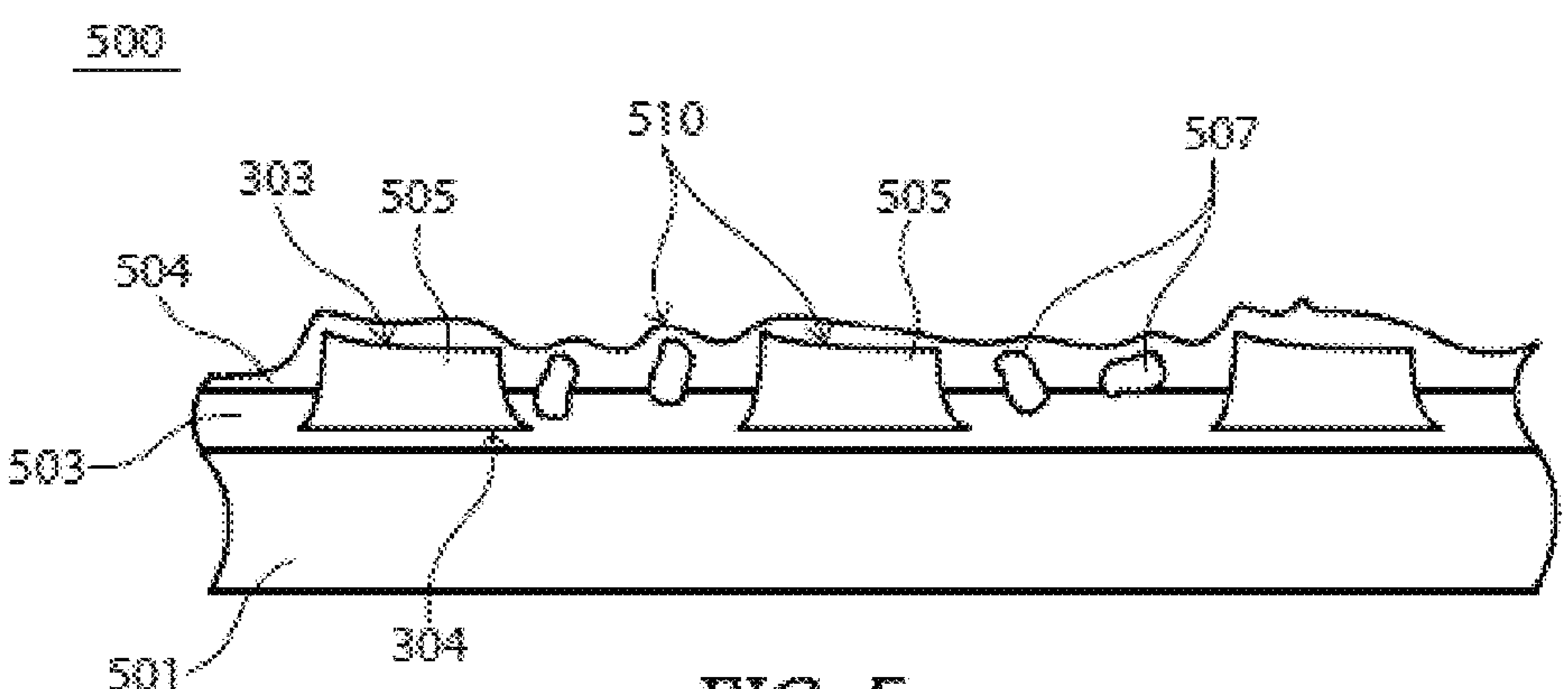
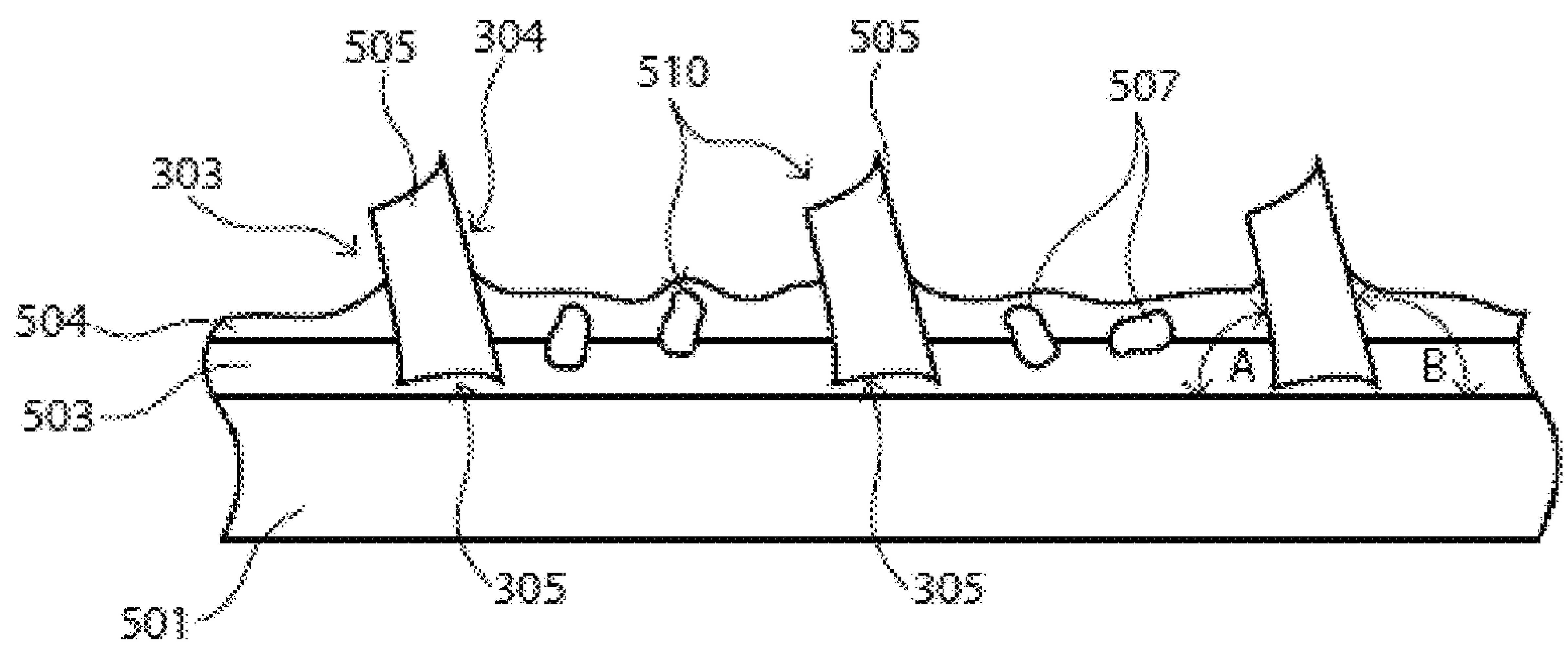


FIG. 5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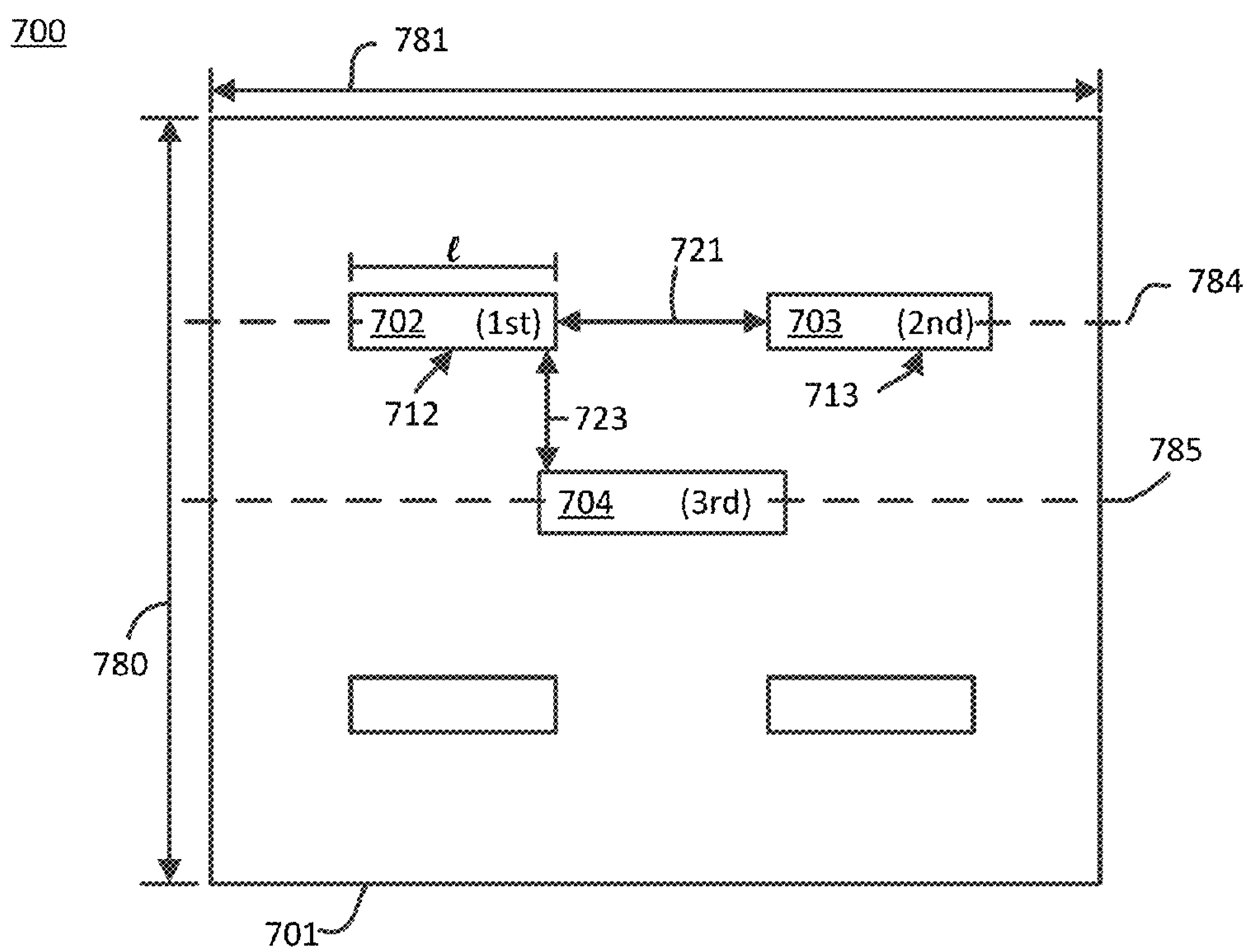
A
B
501
305
305

FIG. 6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781
ℓ
721
784
702 (1st)
703 (2nd)
712
713
723
785
704 (3rd)
780
701

FIG. 7

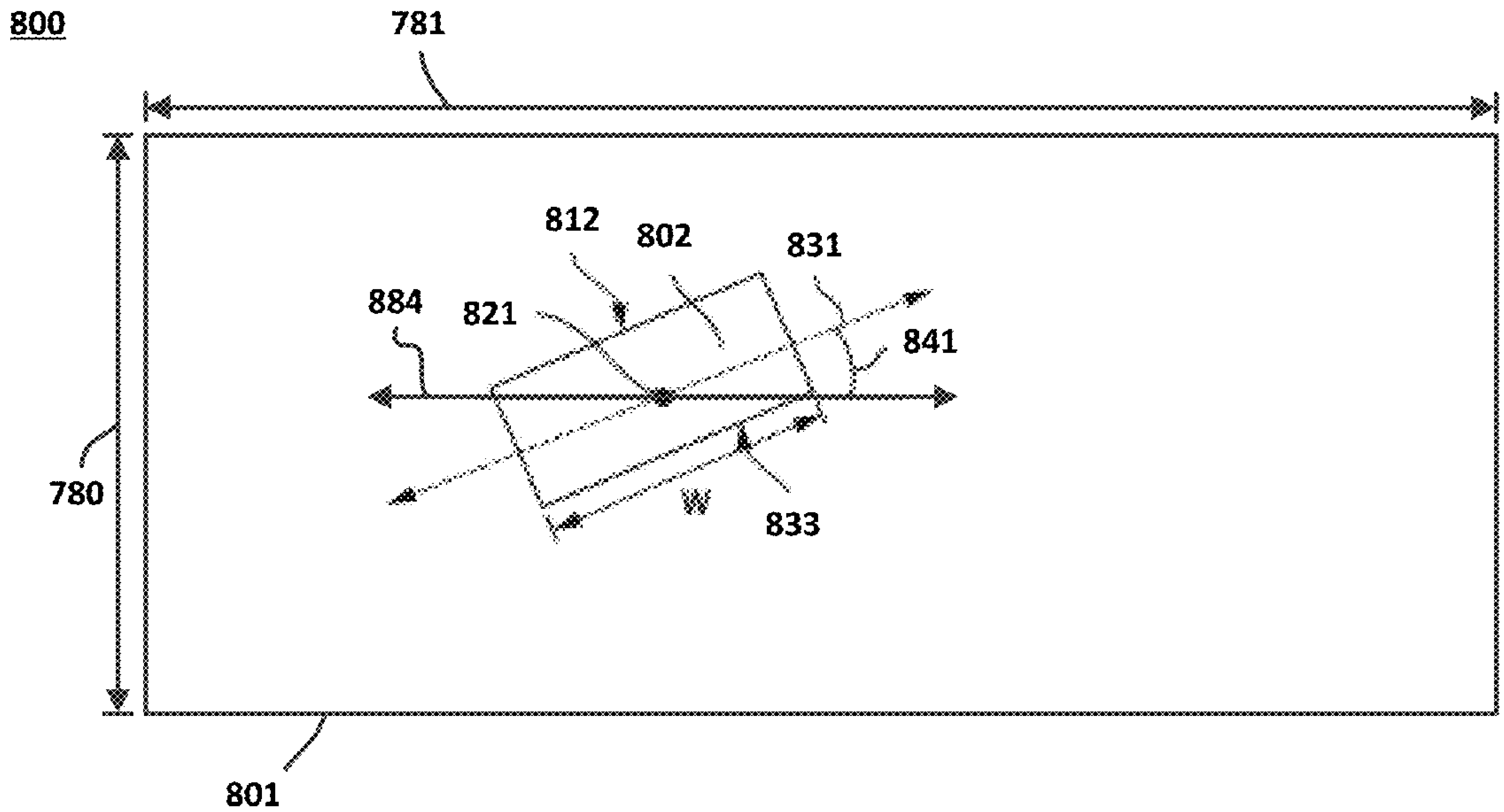
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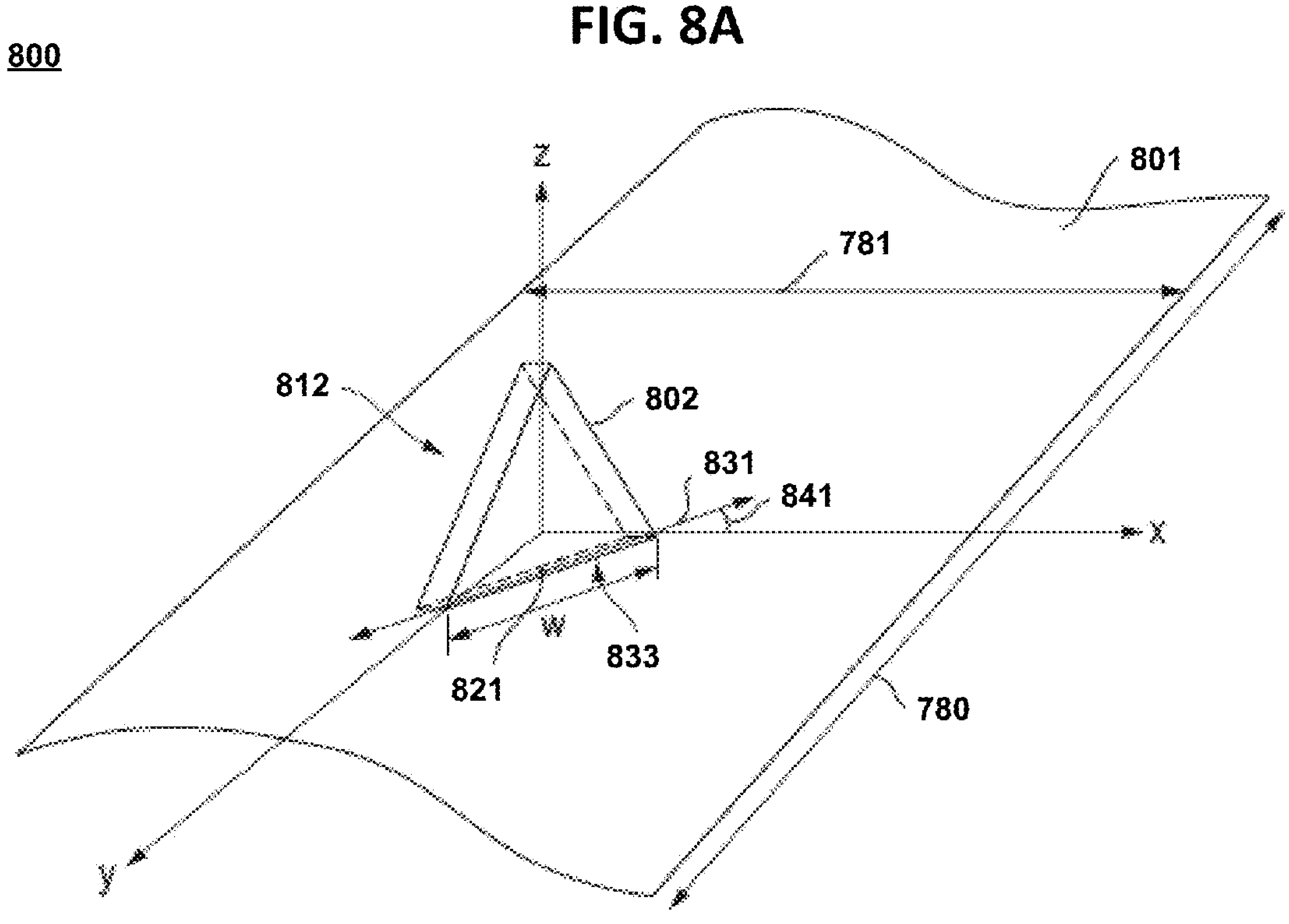
FIG. 8A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812
802
831
841
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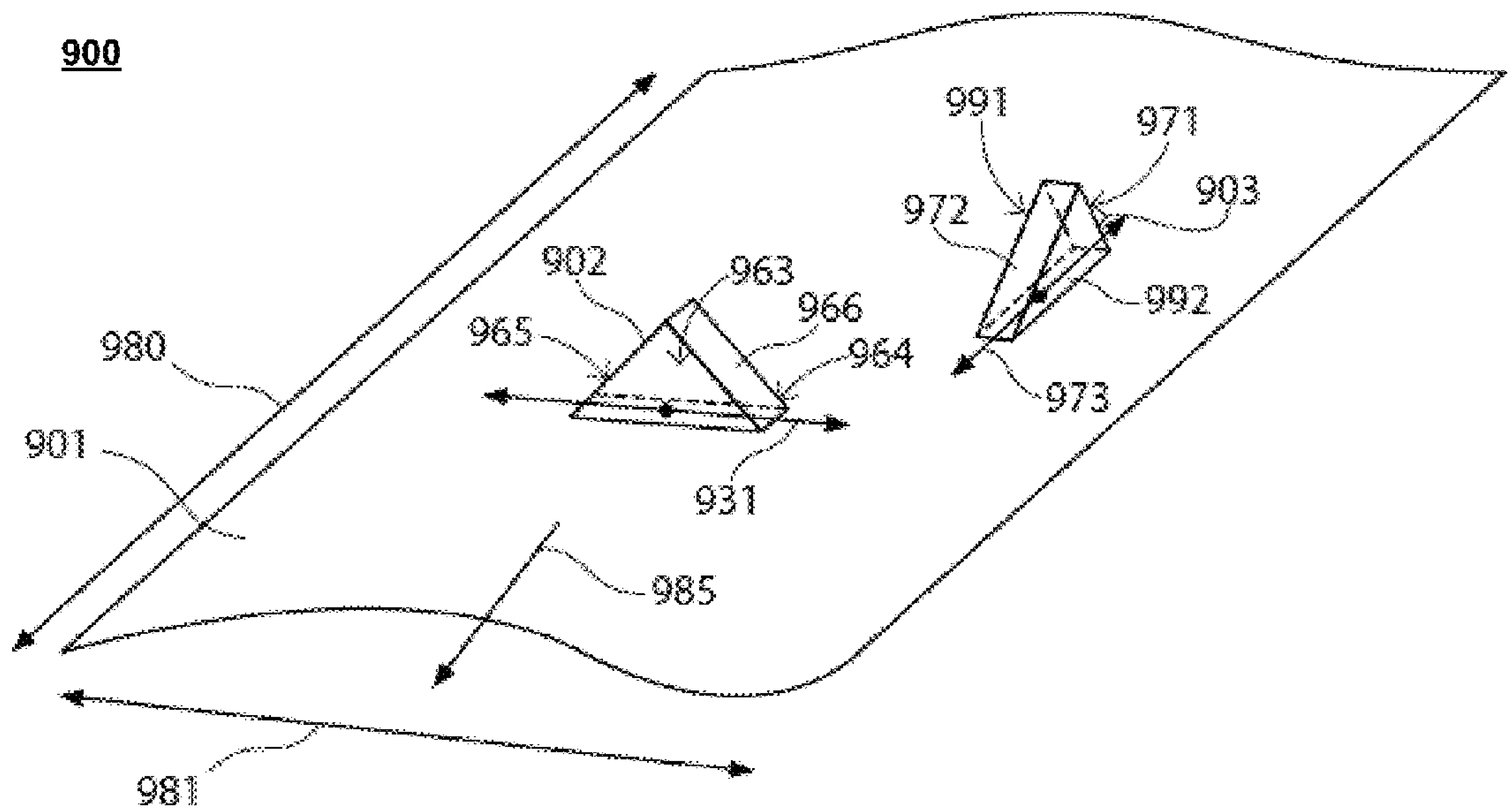
W
833
821
780
y

FIG. 8B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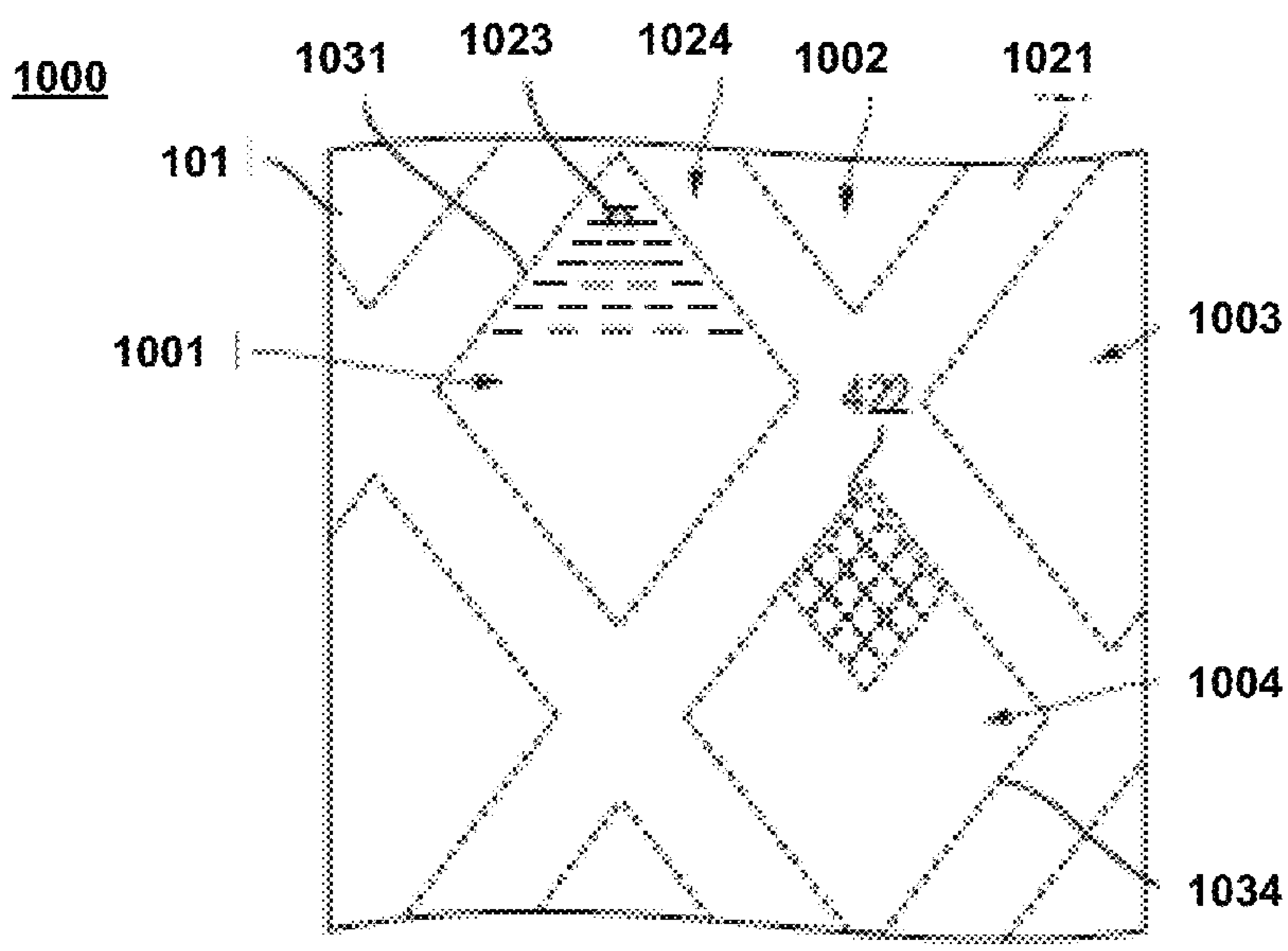
985
981

FIG. 9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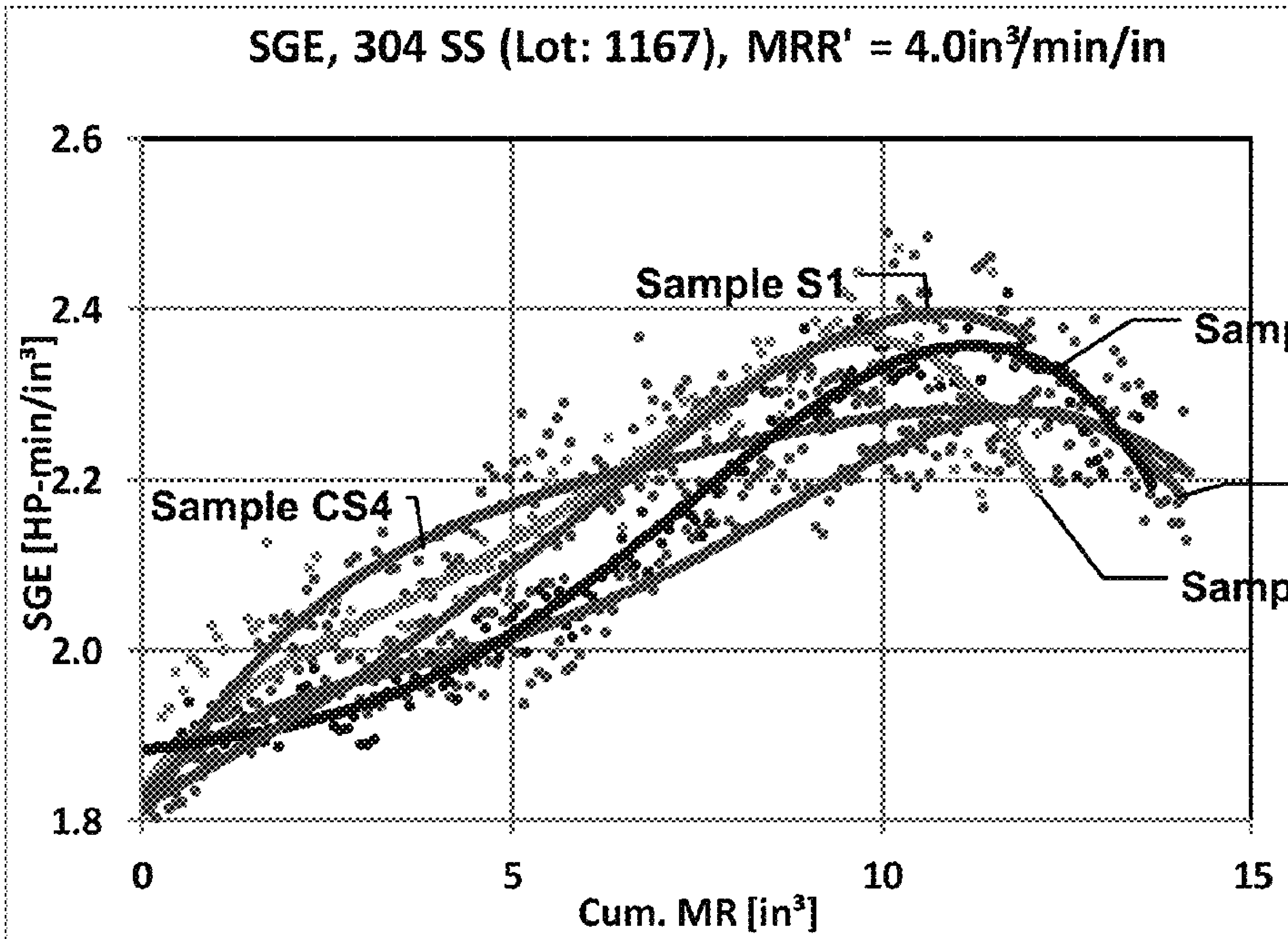
1004
1034

FIG. 10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Cum. MR [in³]
2.6
2.4
2.2
2.0
1.8
0
5
10
15
Sample S1
Sample S2
Sample S3
Sample CS4
Sample CS5

FIG. 11

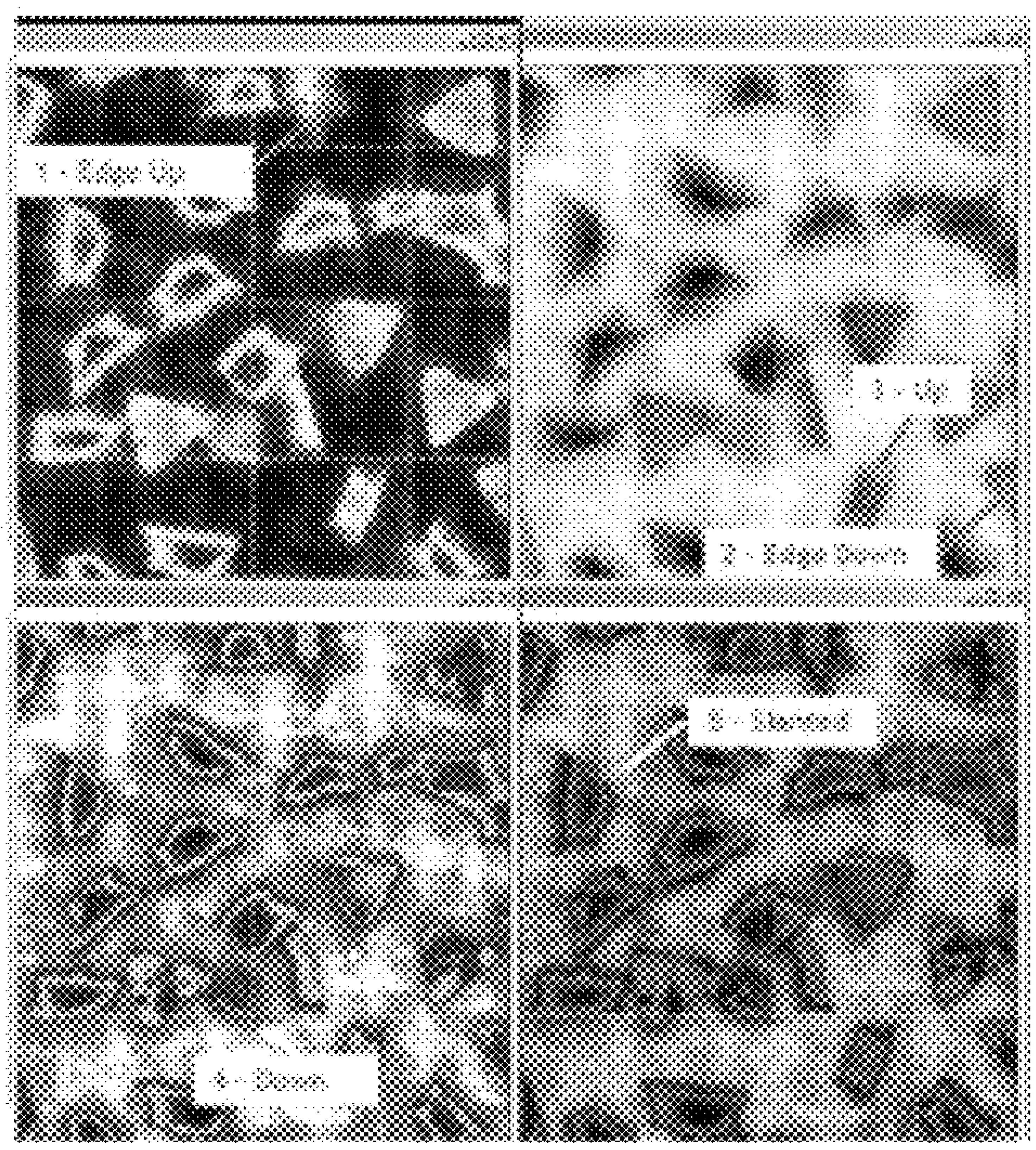
1 - Edge Up
2 - Edge Down

FIG. 12

ABRASIVE ARTICLE INCLUDING SHAPED ABRASIVE PARTICLES

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority under 35 U.S.C. §119(e) to U.S. Patent Application No. 61/922,206 entitled "Abrasive Article Including Shaped Abrasive Particles," by Sujatha Iyengar, filed Dec. 31, 2013, which is assigned to the current assignee hereof and incorporated herein by reference in its entirety.

BACKGROUND

Field of the Disclosure

The following is directed to abrasive articles, and particularly, abrasive articles including shaped abrasive particles.

Description of the Related Art

Abrasive particles and abrasive articles made from abrasive particles are useful for various material removal operations including grinding, finishing, and polishing. Depending upon the type of abrasive material, such abrasive particles can be useful in shaping or grinding a wide variety of materials and surfaces in the manufacturing of goods. Certain types of abrasive particles have been formulated to date that have particular geometries, such as triangular shaped abrasive particles and abrasive articles incorporating such objects. See, for example, U.S. Pat. Nos. 5,201,916; 5,366,523; and 5,984,988.

Three basic technologies that have been employed to produce abrasive particles having a specified shape are (1) fusion, (2) sintering, and (3) chemical ceramic. In the fusion process, abrasive particles can be shaped by a chill roll, the face of which may or may not be engraved, a mold into which molten material is poured, or a heat sink material immersed in an aluminum oxide melt. See, for example, U.S. Pat. No. 3,377,660 (disclosing a process including flowing molten abrasive material from a furnace onto a cool rotating casting cylinder, rapidly solidifying the material to form a thin semisolid curved sheet, densifying the semisolid material with a pressure roll, and then partially fracturing the strip of semisolid material by reversing its curvature by pulling it away from the cylinder with a rapidly driven cooled conveyor).

In the sintering process, abrasive particles can be formed from refractory powders having a particle size of up to 10 micrometers in diameter. Binders can be added to the powders along with a lubricant and a suitable solvent, e.g., water. The resulting mixture, mixtures, or slurries can be shaped into platelets or rods of various lengths and diameters. See, for example, U.S. Pat. No. 3,079,242 (disclosing a method of making abrasive particles from calcined bauxite material including (1) reducing the material to a fine powder, (2) compacting under affirmative pressure and forming the fine particles of said powder into grain sized agglomerations, and (3) sintering the agglomerations of particles at a temperature below the fusion temperature of the bauxite to induce limited recrystallization of the particles, whereby abrasive grains are produced directly to size).

Chemical ceramic technology involves converting a colloidal dispersion or hydrosol (sometimes called a sol), optionally in a mixture, with solutions of other metal oxide precursors, into a gel or any other physical state that restrains the mobility of the components, drying, and firing to obtain a ceramic material. See, for example, U.S. Pat. Nos. 4,744,802 and 4,848,041.

Still, there remains a need in the industry for improving performance, life, and efficacy of abrasive particles, and the abrasive articles that employ abrasive particles.

SUMMARY

A fixed abrasive article including a blend of abrasive particles having a first type of shaped abrasive particle comprising a first height (h**1**), a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height.

A fixed abrasive article comprising a blend of abrasive particles comprising a first type of shaped abrasive particle comprising a first height (h**1**), a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height, and wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11 in^3.

A method of removing material from a workpiece using an abrasive article including a blend of abrasive particles comprising a first type of shaped abrasive particle comprising a first height (h**1**), and a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

FIG. **1**A includes a portion of a system for forming a particulate material in accordance with an embodiment.

FIG. **1**B includes a portion of the system of FIG. **1**A for forming a particulate material in accordance with an embodiment.

FIG. **2** includes a portion of a system for forming a particulate material in accordance with an embodiment.

FIG. **3**A includes a perspective view illustration of a shaped abrasive particle according to an embodiment

FIG. **3**B includes a cross-sectional illustration of the shaped abrasive particle of FIG. **3**A.

FIG. **4** includes a side view of a shaped abrasive particle and percentage flashing according to an embodiment.

FIG. **5** includes a cross-sectional illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **6** includes a cross-sectional illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **7** includes a top-down illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **8**A includes a top-down illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **8**B includes a perspective view illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **9** includes a perspective view illustration of a portion of a coated abrasive article according to an embodiment.

FIG. **10** includes a top view illustration of a portion of an abrasive article in accordance with an embodiment.

FIG. **11** includes a plot of specific grinding energy versus cumulative material removed for a sample corresponding to an embodiment herein and two conventional samples.

FIG. **12** includes images representative of portions of a coated abrasive according to an embodiment and used to analyze the orientation of shaped abrasive particles on the backing.

DETAILED DESCRIPTION

The following is directed to abrasive articles including. The methods herein may be utilized in forming shaped abrasive particles and using abrasive articles incorporating shaped abrasive particles. The shaped abrasive particles may be utilized in various applications, including for example coated abrasives, bonded abrasives, free abrasives, and a combination thereof. Various other uses may be derived for the shaped abrasive particles.

Shaped Abrasive Particles

Various methods may be utilized to obtain shaped abrasive particles. The particles may be obtained from a commercial source or fabricated. Some suitable processes used to fabricate the shaped abrasive particles can include, but is not limited to, screen-printing, molding, pressing, casting, sectioning, cutting, dicing, punching, drying, curing, depositing, coating, extruding, rolling, and a combination thereof.

FIG. **1**A includes an illustration of a system **150** for forming a shaped abrasive particle in accordance with one, non-limiting embodiment. The process of forming shaped abrasive particles can be initiated by forming a mixture **101** including a ceramic material and a liquid. In particular, the mixture **101** can be a gel formed of a ceramic powder material and a liquid, wherein the gel can be characterized as a shape-stable material having the ability to substantially hold a given shape even in the green (i.e., unfired) state. In accordance with an embodiment, the gel can be formed of the ceramic powder material as an integrated network of discrete particles.

The mixture **101** may contain a certain content of solid material, liquid material, and additives such that it has suitable rheological characteristics for use with the process detailed herein. That is, in certain instances, the mixture can have a certain viscosity, and more particularly, suitable rheological characteristics that form a dimensionally stable phase of material that can be formed through the process as noted herein. A dimensionally stable phase of material is a material that can be formed to have a particular shape and substantially maintain the shape for at least a portion of the processing subsequent to forming. In certain instances, the shape may be retained throughout subsequent processing, such that the shape initially provided in the forming process is present in the finally-formed object.

The mixture **101** can be formed to have a particular content of solid material, such as the ceramic powder material. For example, in one embodiment, the mixture **101** can have a solids content of at least about 25 wt %, such as at least about 35 wt %, or even at least about 38 wt % for the total weight of the mixture **101**. Still, in at least one non-limiting embodiment, the solids content of the mixture **101** can be not greater than about 75 wt %, such as not greater than about 70 wt %, not greater than about 65 wt %, not greater than about 55 wt %, not greater than about 45 wt %, or not greater than about 42 wt %. It will be appreciated that the content of the solids materials in the mixture **101** can be within a range between any of the minimum and maximum percentages noted above.

According to one embodiment, the ceramic powder material can include an oxide, a nitride, a carbide, a boride, an oxycarbide, an oxynitride, and a combination thereof. In particular instances, the ceramic material can include alumina. More specifically, the ceramic material may include a boehmite material, which may be a precursor of alpha alumina. The term "boehmite" is generally used herein to denote alumina hydrates including mineral boehmite, typically being $Al_2O_3.H_2O$ and having a water content on the order of 15%, as well as pseudoboehmite, having a water content higher than 15%, such as 20-38% by weight. It is noted that boehmite (including pseudoboehmite) has a particular and identifiable crystal structure, and therefore a unique X-ray diffraction pattern. As such, boehmite is distinguished from other aluminous materials including other hydrated aluminas such as ATH (aluminum trihydroxide), a common precursor material used herein for the fabrication of boehmite particulate materials.

Furthermore, the mixture **101** can be formed to have a particular content of liquid material. Some suitable liquids may include water. In accordance with one embodiment, the mixture **101** can be formed to have a liquid content less than the solids content of the mixture **101**. In more particular instances, the mixture **101** can have a liquid content of at least about 25 wt % for the total weight of the mixture **101**. In other instances, the amount of liquid within the mixture **101** can be greater, such as at least about 35 wt %, at least about 45 wt %, at least about 50 wt %, or even at least about 58 wt %. Still, in at least one non-limiting embodiment, the liquid content of the mixture can be not greater than about 75 wt %, such as not greater than about 70 wt %, not greater than about 65 wt %, not greater than about 62 wt %, or even not greater than about 60 wt %. It will be appreciated that the content of the liquid in the mixture **101** can be within a range between any of the minimum and maximum percentages noted above.

Furthermore, to facilitate processing and forming shaped abrasive particles according to embodiments herein, the mixture **101** can have a particular storage modulus. For example, the mixture **101** can have a storage modulus of at least about 1×10^4 Pa, such as at least about 4×10^4 Pa, or even at least about 5×10^4 Pa. However, in at least one non-limiting embodiment, the mixture **101** may have a storage modulus of not greater than about 1×10^7 Pa, such as not greater than about 2×10^6 Pa. It will be appreciated that the storage modulus of the mixture **101** can be within a range between any of the minimum and maximum values noted above.

The storage modulus can be measured via a parallel plate system using ARES or AR-G2 rotational rheometers, with Peltier plate temperature control systems. For testing, the mixture **101** can be extruded within a gap between two plates that are set to be approximately 8 mm apart from each other. After extruding the gel into the gap, the distance between the two plates defining the gap is reduced to 2 mm until the mixture **101** completely fills the gap between the plates. After wiping away excess mixture, the gap is decreased by 0.1 mm and the test is initiated. The test is an oscillation strain sweep test conducted with instrument settings of a strain range between 0.01% to 100%, at 6.28 rad/s (1 Hz), using 25-mm parallel plate and recording 10 points per decade. Within 1 hour after the test completes, the gap is lowered again by 0.1 mm and the test is repeated. The test can be repeated at least 6 times. The first test may differ from the second and third tests. Only the results from the second and third tests for each specimen should be reported.

Furthermore, to facilitate processing and forming shaped abrasive particles according to embodiments herein, the mixture **101** can have a particular viscosity. For example, the mixture **101** can have a viscosity of at least about 4×10^3 Pa s, at least about 5×10^3 Pa s, at least about 6×10^3 Pa s, at least about 8×10^3 Pa s, at least about 10×10^3 Pa s, at least about 20×10^3 Pa s, at least about 30×10^3 Pa s, at least about 40×10^3 Pa s, at least about 50×10^3 Pa s, at least about 60×10^3 Pa s, or at least about 65×10^3 Pa s. In at least one non-limiting embodiment, the mixture **101** may have a viscosity of not greater than about 100×10^3 Pa s, such as not greater than about 95×10^3 Pa s, not greater than about 90×10^3 Pa s, or even not greater than about 85×10^3 Pa s. It will be appreciated that the viscosity of the mixture **101** can be within a range between any of the minimum and maximum values noted above. The viscosity can be measured in the same manner as the storage modulus as described above.

Moreover, the mixture **101** can be formed to have a particular content of organic materials including, for example, organic additives that can be distinct from the liquid to facilitate processing and formation of shaped abrasive particles according to the embodiments herein. Some suitable organic additives can include stabilizers, binders such as fructose, sucrose, lactose, glucose, UV curable resins, and the like.

Notably, the embodiments herein may utilize a mixture **101** that can be distinct from slurries used in conventional forming operations. For example, the content of organic materials within the mixture **101** and, in particular, any of the organic additives noted above, may be a minor amount as compared to other components within the mixture **101**. In at least one embodiment, the mixture **101** can be formed to have not greater than about 30 wt % organic material for the total weight of the mixture **101**. In other instances, the amount of organic materials may be less, such as not greater than about 15 wt %, not greater than about 10 wt %, or even not greater than about 5 wt %. Still, in at least one non-limiting embodiment, the amount of organic materials within the mixture **101** can be at least about 0.01 wt %, such as at least about 0.5 wt % for the total weight of the mixture **101**. It will be appreciated that the amount of organic materials in the mixture **101** can be within a range between any of the minimum and maximum values noted above.

Moreover, the mixture **101** can be formed to have a particular content of acid or base, distinct from the liquid content, to facilitate processing and formation of shaped abrasive particles according to the embodiments herein. Some suitable acids or bases can include nitric acid, sulfuric acid, citric acid, chloric acid, tartaric acid, phosphoric acid, ammonium nitrate, and ammonium citrate. According to one particular embodiment in which a nitric acid additive is used, the mixture **101** can have a pH of less than about 5, and more particularly, can have a pH within a range between about 2 and about 4.

The system **150** of FIG. **1**A, can include a die **103**. As illustrated, the mixture **101** can be provided within the interior of the die **103** and configured to be extruded through a die opening **105** positioned at one end of the die **103**. As further illustrated, extruding can include applying a force **180** (such as a pressure) on the mixture **101** to facilitate extruding the mixture **101** through the die opening **105**. In an embodiment, the system **150** can generally be referred to as a screen printing process. During extrusion within an application zone **183**, a screen **151** can be in direct contact with a portion of a belt **109**. The screen printing process can include extruding the mixture **101** from the die **103** through the die opening **105** in a direction **191**. In particular, the screen printing process may utilize the screen **151** such that, upon extruding the mixture **101** through the die opening **105**, the mixture **101** can be forced into an opening **152** in the screen **151**.

In accordance with an embodiment, a particular pressure may be utilized during extrusion. For example, the pressure can be at least about 10 kPa, such as at least about 500 kPa. Still, in at least one non-limiting embodiment, the pressure utilized during extrusion can be not greater than about 4 MPa. It will be appreciated that the pressure used to extrude the mixture **101** can be within a range between any of the minimum and maximum values noted above. In particular instances, the consistency of the pressure delivered by a piston **199** may facilitate improved processing and formation of shaped abrasive particles. Notably, controlled delivery of consistent pressure across the mixture **101** and across the width of the die **103** can facilitate improved processing control and improved dimensional characteristics of the shaped abrasive particles.

Referring briefly to FIG. **1**B, a portion of the screen **151** is illustrated. As shown, the screen **151** can include the opening **152**, and more particularly, a plurality of openings **152** extending through the volume of the screen **151**. In accordance with an embodiment, the openings **152** can have a two-dimensional shape as viewed in a plane defined by the length (l) and width (w) of the screen. The two-dimensional shape can include various shapes such as, for example, polygons, ellipsoids, numerals, Greek alphabet letters, Latin alphabet letters, Russian alphabet characters, complex shapes including a combination of polygonal shapes, and a combination thereof. In particular instances, the openings **152** may have two-dimensional polygonal shapes such as a triangle, a rectangle, a quadrilateral, a pentagon, a hexagon, a heptagon, an octagon, a nonagon, a decagon, and a combination thereof.

As further illustrated, the screen **151** can have openings **152** that are oriented in a particular manner relative to each other. As illustrated and in accordance with one embodiment, each of the openings **152** can have substantially the same orientation relative to each other, and substantially the same orientation relative to the surface of the screen. For example, each of the openings **152** can have a first edge **154** defining a first plane **155** for a first row **156** of the openings **152** extending laterally across a lateral axis **158** of the screen **151**. The first plane **155** can extend in a direction substantially orthogonal to a longitudinal axis **157** of the screen **151**. However, it will be appreciated, that in other instances, the openings **152** need not necessarily have the same orientation relative to each other.

Moreover, the first row **156** of openings **152** can be oriented relative to a direction of translation to facilitate particular processing and controlled formation of shaped abrasive particles. For example, the openings **152** can be arranged on the screen **151** such that the first plane **155** of the first row **156** defines an angle relative to the direction of translation **171**. As illustrated, the first plane **155** can define an angle that is substantially orthogonal to the direction of translation **171**. Still, it will be appreciated that in one embodiment, the openings **152** can be arranged on the screen **151** such that the first plane **155** of the first row **156** defines a different angle with respect to the direction of translation, including for example, an acute angle or an obtuse angle. Still, it will be appreciated that the openings **152** may not necessarily be arranged in rows. The openings **152** may be arranged in various particular ordered distributions with respect to each other on the screen **151**, such as in the form of a two-dimensional pattern. Alternatively, the openings may be disposed in a random manner on the screen **151**.

Referring again to FIG. **1**A, after forcing the mixture **101** through the die opening **105** and a portion of the mixture **101** through the openings **152** in the screen **151**, one or more precursor shaped abrasive particles **123** may be printed on the belt **109** disposed under the screen **151**. According to a particular embodiment, the precursor shaped abrasive particles **123** can have a shape substantially replicating the shape of the openings **152**. Notably, the mixture **101** can be forced through the screen in rapid fashion, such that the average residence time of the mixture **101** within the openings **152** can be less than about 2 minutes, less than about 1 minute, less than about 40 seconds, or even less than about 20 seconds. In particular non-limiting embodiments, the mixture **101** may be substantially unaltered during printing as it travels through the screen openings **152**, thus experiencing no change in the amount of components from the original mixture, and may experience no appreciable drying in the openings **152** of the screen **151**.

Additionally, the system **151** can include a bottom stage **198** within the application zone **183**. During the process of forming shaped abrasive particles, the belt **109** can travel over the bottom stage **198**, which can offer a suitable substrate for forming. According to one embodiment, the bottom stage **198** can include a particularly rigid construction including, for example, an inorganic material such as a metal or metal alloy having a construction suited to facilitating the formation of shaped abrasive particles according to embodiments herein. Moreover, the bottom stage **198** can have an upper surface that is in direct contact with the belt **109** and that has a particular geometry and/or dimension (e.g., flatness, surface roughness, etc.), which can also facilitate improved control of dimensional characteristics of the shaped abrasive particles.

During operation of the system **150**, the screen **151** can be translated in a direction **153** while the belt **109** can be translated in a direction **110** substantially similar to the direction **153**, at least within the application zone **183**, to facilitate a continuous printing operation. As such, the precursor shaped abrasive particles **123** may be printed onto the belt **109** and translated along the belt **109** to undergo further processing. It will be appreciated that such further processing can include processes described in the embodiments herein, including for example, shaping, application of other materials (e.g., dopant material), drying, and the like.

In some embodiments, the belt **109** and/or the screen **151** can be translated while extruding the mixture **101** through the die opening **105**. As illustrated in the system **100**, the mixture **101** may be extruded in a direction **191**. The direction of translation **110** of the belt **109** and/or the screen **151** can be angled relative to the direction of extrusion **191** of the mixture **101**. While the angle between the direction of translation **110** and the direction of extrusion **191** is illustrated as substantially orthogonal in the system **100**, other angles are contemplated, including for example, an acute angle or an obtuse angle.

The belt **109** and/or the screen **151** may be translated at a particular rate to facilitate processing. For example, the belt **109** and/or the screen **151** may be translated at a rate of at least about 3 cm/s. In other embodiments, the rate of translation of the belt **109** and/or the screen **151** may be greater, such as at least about 4 cm/s, at least about 6 cm/s, at least about 8 cm/s, or even at least about 10 cm/s. Still, in at least one non-limiting embodiment, the belt **109** and/or the screen **151** may be translated in a direction **110** at a rate of not greater than about 5 m/s, not greater than about 1 m/s, or even not greater than about 0.5 m/s. It will be appreciated that the belt **109** and/or the screen **151** may be translated at a rate within a range between any of the minimum and maximum values noted above, and moreover, may be translated at substantially the same rate relative to each other. Furthermore, for certain processes according to embodiments herein, the rate of translation of the belt **109** as compared to the rate of extrusion of the mixture **101** in the direction **191** may be controlled to facilitate proper processing.

After the mixture **101** is extruded through the die opening **105**, the mixture **101** may be translated along the belt **109** under a knife edge **107** attached to a surface of the die **103**. The knife edge **107** may define a region at the front of the die **103** that facilitates displacement of the mixture **101** into the openings **152** of the screen **151**.

Certain processing parameters may be controlled to facilitate formation of particular features of the precursor shaped abrasive particles **123** and the finally-formed shaped abrasive particles described herein. Some exemplary process parameters that can be controlled include a release distance **197**, a viscosity of the mixture, a storage modulus of the mixture, mechanical properties of the bottom stage, geometric or dimensional characteristics of the bottom stage, thickness of the screen, rigidity of the screen, a solid content of the mixture, a carrier content of the mixture, a release angle, a translation speed, a temperature, a content of release agent, a pressure exerted on the mixture, a speed of the belt, and a combination thereof.

According to one embodiment, one particular process parameter can include controlling the release distance **197** between a filling position and a release position. In particular, the release distance **197** can be a distance measured in a direction **110** of the translation of the belt **109** between the end of the die **103** and the initial point of separation between the screen **151** and the belt **109**. According to one embodiment, controlling the release distance **197** can affect at least one dimensional characteristic of the precursor shaped abrasive particles **123** or the finally-formed shaped abrasive particles. Moreover, control of the release distance **197** can affect a combination of dimensional characteristics of the shaped abrasive particles, including but not limited to, length, width, interior height (hi), variation of interior height (Vhi), difference in height, profile ratio, flashing index, dishing index, rake angle, any of the dimensional characteristic variations of the embodiments herein, and a combination thereof.

According to one embodiment, the release distance **197** can be not greater than a length of the screen **151**. In other instances, the release distance **197** can be not greater than a width of the screen **151**. Still, in one particular embodiment, the release distance **197** can be not greater than 10 times a largest dimension of the opening **152** in the screen **151**. For example, the openings **152** can have a triangular shape, such as illustrated in FIG. 1B, and the release distance **197** can be not greater than 10 times the length of one side of the opening **152** defining the triangular shape. In other instances, the release distance **197** can be less, such as not greater than about 8 times the largest dimension of the opening **152** in the screen **151**, such as not greater than about 5 times, not greater than about 3 times, not greater than about 2 times, or even not greater than the largest dimension of the opening **152** in the screen **151**.

In more particular instances, the release distance **197** can be not greater than about 30 mm, such as not greater than about 20 mm, or even not greater than about 10 mm. For at least one embodiment, the release distance can be substantially zero, and more particularly, can be essentially zero. Accordingly, the mixture **101** can be disposed into the openings **152** within the application zone **183** and the screen **151** and the belt **109** may be separating from each other at the end of the die **103** or even before the end of the die **103**.

According to one particular method of forming, the release distance **197** can be essentially zero, which may facilitate substantially simultaneous filling of the openings **152** with the mixture **101** and separation between the belt **109** and the screen **151**. For example, before the screen **151** and the belt **109** pass the end of the die **103** and exit the application zone **183**, separation of the screen **151** and the belt **109** may be initiated. In more particular embodiments, separation between the screen **151** and the belt **109** may be initiated immediately after the openings **152** are filled with the mixture **101**, prior to leaving the application zone **183** and while the screen **151** is located under the die **103**. In still another embodiment, separation between the screen **151** and the belt **109** may be initiated while the mixture **101** is being placed within the opening **152** of the screen **151**. In an alternative embodiment, separation between the screen **151** and the belt **109** can be initiated before the mixture **101** is placed in the openings **152** of the screen **151**. For example, before the openings **152** pass under the die opening **105**, the belt **109** and screen **151** are being separated, such that a gap exists between belt **109** and the screen **151** while the mixture **101** is being forced into the openings **152**.

For example, FIG. **2** illustrates a printing operation where the release distance **197** is substantially zero and separation between the belt **109** and the screen **151** is initiated before the belt **109** and screen **151** pass under the die opening **105**. More particularly, the release between the belt **109** and the screen **151** is initiated as the belt **109** and screen **151** enter the application zone **183** and pass under the front of the die **103**. Still, it will be appreciated that in some embodiments, separation of the belt **109** and screen **151** can occur before the belt **109** and screen **151** enter the application zone **183** (defined by the front of the die **103**), such that the release distance **197** may be a negative value.

Control of the release distance **197** can facilitate controlled formation of shaped abrasive particles having improved dimensional characteristics and improved dimensional tolerances (e.g., low dimensional characteristic variability). For example, decreasing the release distance **197** in combination with controlling other processing parameters can facilitate improved formation of shaped abrasive particles having greater interior height (hi) values.

Additionally, as illustrated in FIG. **2**, control of the separation height **196** between a surface of the belt **109** and a lower surface **198** of the screen **151** may facilitate controlled formation of shaped abrasive particles having improved dimensional characteristics and improved dimensional tolerances (e.g., low dimensional characteristic variability). The separation height **196** may be related to the thickness of the screen **151**, the distance between the belt **109** and the die **103**, and a combination thereof. Moreover, one or more dimensional characteristics (e.g., interior height) of the precursor shaped abrasive particles **123** may be controlled by controlling the separation height **196** and the thickness of the screen **151**. In particular instances, the screen **151** can have an average thickness of not greater than about 700 microns, such as not greater than about 690 microns, not greater than about 680 microns, not greater than about 670 microns, not greater than about 650 microns, or not greater than about 640 microns. Still, the average thickness of the screen can be at least about 100 microns, such as at least about 300 microns, or even at least about 400 microns.

In one embodiment the process of controlling can include a multi-step process that can include measuring, calculating, adjusting, and a combination thereof. Such processes can be applied to the process parameter, a dimensional characteristic, a combination of dimensional characteristics, and a combination thereof. For example, in one embodiment, controlling can include measuring one or more dimensional characteristics, calculating one or more values based on the process of measuring the one or more dimensional characteristics, and adjusting one or more process parameters (e.g., the release distance **197**) based on the one or more calculated values. The process of controlling, and particularly any of the processes of measuring, calculating, and adjusting may be completed before, after, or during the formation of the shaped abrasive particles. In one particular embodiment, the controlling process can be a continuous process, wherein one or more dimensional characteristics are measured and one or more process parameters are changed (i.e., adjusted) in response to the measured dimensional characteristics. For example, the process of controlling can include measuring a dimensional characteristic such as a difference in height of the precursor shaped abrasive particles **123**, calculating a difference in height value of the precursor shaped abrasive particles **123**, and changing the release distance **197** to change the difference in height value of the precursor shaped abrasive particles **123**.

Referring again to FIG. **1**, after extruding the mixture **101** into the openings **152** of the screen **151**, the belt **109** and the screen **151** may be translated to a release zone **185** where the belt **109** and the screen **151** can be separated to facilitate the formation of the precursor shaped abrasive particles **123**. In accordance with an embodiment, the screen **151** and the belt **109** may be separated from each other within the release zone **185** at a particular release angle.

In fact, as illustrated, the precursor shaped abrasive particles **123** may be translated through a series of zones wherein various treating processes may be conducted. Some suitable exemplary treating processes can include drying, heating, curing, reacting, radiating, mixing, stirring, agitating, planarizing, calcining, sintering, comminuting, sieving, doping, and a combination thereof. According to one embodiment, the precursor shaped abrasive particles **123** may be translated through an optional shaping zone **113**, wherein at least one exterior surface of the particles may be shaped as described in embodiments herein. Furthermore, the precursor shaped abrasive particles **123** may be translated through an optional application zone **131**, wherein a dopant material can be applied to at least one exterior surface of the particles as described in embodiments herein. And further, the precursor shaped abrasive particles **123** may be translated on the belt **109** through an optional post-forming zone **125**, wherein a variety of processes, including for example, drying, may be conducted on the precursor shaped abrasive particles **123** as described in embodiments herein.

The application zone **131** may be used for applying a material to at least one exterior surface of one or more precursor shaped abrasive particles **123**. In accordance with an embodiment, a dopant material may be applied to the precursor shaped abrasive particles **123**. More particularly, as illustrated in FIG. **1**, the application zone **131** can be positioned before the post-forming zone **125**. As such, the process of applying a dopant material may be completed on the precursor shaped abrasive particles **123**. However, it will be appreciated that the application zone **131** may be positioned in other places within the system **100**. For example, the process of applying a dopant material can be completed after forming the precursor shaped abrasive particles **123**, and more particularly, after the post-forming zone **125**. In yet other instances, which will be described in more detail herein, the process of applying a dopant material may be conducted simultaneously with a process of forming the precursor shaped abrasive particles **123**.

Within the application zone **131**, a dopant material may be applied utilizing various methods including for example, spraying, dipping, depositing, impregnating, transferring, punching, cutting, pressing, crushing, and any combination thereof. In particular instances, the application zone **131** may utilize a spray nozzle, or a combination of spray nozzles **132** and **133** to spray dopant material onto the precursor shaped abrasive particles **123**.

In accordance with an embodiment, applying a dopant material can include the application of a particular material, such as a precursor. In certain instances, the precursor can be a salt, such as a metal salt, that includes a dopant material to be incorporated into the finally-formed shaped abrasive particles. For example, the metal salt can include an element or compound that is the precursor to the dopant material. It will be appreciated that the salt material may be in liquid form, such as in a dispersion comprising the salt and liquid carrier. The salt may include nitrogen, and more particularly, can include a nitrate. In other embodiments, the salt can be a chloride, sulfate, phosphate, and a combination thereof. In one embodiment, the salt can include a metal nitrate, and more particularly, consist essentially of a metal nitrate.

In one embodiment, the dopant material can include an element or compound such as an alkali element, alkaline earth element, rare earth element, hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, or a combination thereof. In one particular embodiment, the dopant material includes an element or compound including an element such as lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, niobium, hafnium, zirconium, tantalum, molybdenum, vanadium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof.

In particular instances, the process of applying a dopant material can include selective placement of the dopant material on at least one exterior surface of a precursor shaped abrasive particle **123**. For example, the process of applying a dopant material can include the application of a dopant material to an upper surface or a bottom surface of the precursor shaped abrasive particles **123**. In still another embodiment, one or more side surfaces of the precursor shaped abrasive particles **123** can be treated such that a dopant material is applied thereto. It will be appreciated that various methods may be used to apply the dopant material to various exterior surfaces of the precursor shaped abrasive particles **123**. For example, a spraying process may be used to apply a dopant material to an upper surface or side surface of the precursor shaped abrasive particles **123**. Still, in an alternative embodiment, a dopant material may be applied to the bottom surface of the precursor shaped abrasive particles **123** through a process such as dipping, depositing, impregnating, or a combination thereof. It will be appreciated that a surface of the belt **109** may be treated with dopant material to facilitate a transfer of the dopant material to a bottom surface of precursor shaped abrasive particles **123**.

After forming precursor shaped abrasive particles **123**, the particles may be translated through a post-forming zone **125**. Various processes may be conducted in the post-forming zone **125**, including treatment of the precursor shaped abrasive particles **123**. In one embodiment, the post-forming zone **125** can include a heating process where the precursor shaped abrasive particles **123** may be dried. Drying may include removal of a particular content of material, including volatiles, such as water. In accordance with an embodiment, the drying process can be conducted at a drying temperature of not greater than about 300° C., such as not greater than about 280° C., or even not greater than about 250° C. Still, in one non-limiting embodiment, the drying process may be conducted at a drying temperature of at least about 50° C. It will be appreciated that the drying temperature may be within a range between any of the minimum and maximum temperatures noted above. Furthermore, the precursor shaped abrasive particles **123** may be translated through the post-forming zone **125** at a particular rate, such as at least about 0.2 feet/min and not greater than about 8 feet/min.

Furthermore, the drying process may be conducted for a particular duration. For example, the drying process may be not greater than about six hours.

After the precursor shaped abrasive particles **123** are translated through the post-forming zone **125**, the precursor shaped abrasive particles **123** may be removed from the belt **109**. The precursor shaped abrasive particles **123** may be collected in a bin **127** for further processing.

In accordance with an embodiment, the process of forming shaped abrasive particles may further comprise a sintering process. For certain processes of embodiments herein, sintering can be conducted after collecting the precursor shaped abrasive particles **123** from the belt **109**. Alternatively, the sintering may be a process that is conducted while the precursor shaped abrasive particles **123** are on the belt **109**. Sintering of the precursor shaped abrasive particles **123** may be utilized to densify the particles, which are generally in a green state. In a particular instance, the sintering process can facilitate the formation of a high-temperature phase of the ceramic material. For example, in one embodiment, the precursor shaped abrasive particles **123** may be sintered such that a high-temperature phase of alumina, such as alpha alumina, is formed. In one instance, a shaped abrasive particle can comprise at least about 90 wt % alpha alumina for the total weight of the particle. In other instances, the content of alpha alumina may be greater such that the shaped abrasive particle may consist essentially of alpha alumina.

Additionally, the body of the finally-formed shaped abrasive particles can have particular two-dimensional shapes. For example, the body can have a two-dimensional shape, as viewed in a plane defined by the length and width of the body, and can have a shape including a polygonal shape, ellipsoidal shape, a numeral, a Greek alphabet character, a Latin alphabet character, a Russian alphabet character, a complex shape utilizing a combination of polygonal shapes and a combination thereof. Particular polygonal shapes include triangular, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, nonagonal, decagonal, and any combination thereof. In another embodiment, the body can include a two-dimensional shape, as viewed in a plane defined by a length and a width of the body, including shapes selected from the group consisting of ellipsoids, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, and a combination thereof.

FIG. **3**A includes a perspective view illustration of a shaped abrasive particle **300** in accordance with an embodiment. Additionally, FIG. **3**B includes a cross-sectional illustration of the abrasive particle of FIG. **3**A. A body **301** of the shaped abrasive particle **300** includes an upper major surface **303** (i.e., a first major surface) and a bottom major surface **304** (i.e., a second major surface) opposite the upper major surface **303**. The upper surface **303** and the bottom surface **304** can be separated from each other by side surfaces **305**, **306**, and **307**. As illustrated, the body **301** of the shaped abrasive particle **300** can have a generally triangular shape as viewed in a plane of the upper surface **303**. In particular, the body **301** can have a length (Lmiddle) as shown in FIG. **3**B, which may be measured at the bottom surface **304** of the body **301** as extending from a corner **313** through a midpoint **381** of the body **301** to a midpoint at the opposite edge **314** of the body. Alternatively, the body **301** can be defined by a second length or profile length (Lp), which is the measure of the dimension of the body **301** from a side view at the upper surface **303** from a first corner **313** to an adjacent corner **312**. Notably, the dimension of Lmiddle can be a length defining a distance between a height at a corner (hc) and a height at a midpoint edge (hm) opposite the corner. The dimension Lp can be a profile length along a side of the particle **300** (as seen from a side view such as shown in FIGS. **2**A and **2**B) defining the distance between hl and h**2**. Reference herein to the length can refer to either Lmiddle or Lp.

The body **301** can further include a width (w) that is the longest dimension of the body **301** and extending along a side. The body **301** can further include a height (h), which may be a dimension of the body **301** extending in a direction perpendicular to the length and width in a direction defined by a side surface of the body **301**. Notably, as will be described in more detail herein, the body **301** can be defined by various heights depending upon the location on the body **301**. In specific instances, the width can be greater than or equal to the length, the length can be greater than or equal to the height, and the width can be greater than or equal to the height.

Moreover, reference herein to any of the features of the embodiments herein, including dimensional characteristic (e.g., h**1**, h**2**, hi, w, Lmiddle, Lp, and the like), can be reference to a dimension of a single shaped abrasive particle of a batch, a median value, or an average value derived from analysis of a suitable sampling of shaped abrasive particles from a batch. Unless stated explicitly, reference herein to a dimensional characteristic can be considered reference to a median value that is a based on a statistically significant value derived from a sample size of a suitable number of particles from a batch of particles. Notably, for certain embodiments herein, the sample size can include at least 10 randomly selected particles from a batch of particles. A batch of particles may include an amount of shaped abrasive particles suitable for forming a commercial grade abrasive product, such as at least about 20 lbs. The batch of particles may be, but need not necessarily be, a group of particles that are collected from a single process run.

In accordance with an embodiment, the body **301** of the shaped abrasive particle can have a first corner height (hc) at a first region of the body defined by a corner **313**. Notably, the corner **313** may represent the point of greatest height on the body **301**, however, the height at the corner **313** does not necessarily represent the point of greatest height on the body **301**. The corner **313** can be defined as a point or region on the body **301** defined by the joining of the upper surface **303**, and two side surfaces **305** and **307**. The body **301** may further include other corners, spaced apart from each other, including for example, corner **311** and corner **312**. As further illustrated, the body **301** can include edges **314**, **315**, and **316** that can be separated from each other by the corners **311**, **312**, and **313**. The edge **314** can be defined by an intersection of the upper surface **303** with the side surface **306**. The edge **315** can be defined by an intersection of the upper surface **303** and side surface **305** between corners **311** and **313**. The edge **316** can be defined by an intersection of the upper surface **303** and side surface **307** between corners **312** and **313**.

As further illustrated, the body **301** can include a second midpoint height (hm) at a second end of the body **301**, which can be defined by a region at the midpoint of the edge **314**, which can be opposite the first end defined by the corner **313**. The axis **350** can extend between the two ends of the body **301**. FIG. **3**B is a cross-sectional illustration of the body **301** along the axis **350**, which can extend through a midpoint **381** of the body **301** along the dimension of length (Lmiddle) between the corner **313** and the midpoint of the edge **314**.

In accordance with an embodiment, the shaped abrasive particles of the embodiments herein, including for example, the particle of FIGS. **3**A and **3**B can have an average difference in height, which is a measure of the difference between hc and hm. For convention herein, average difference in height will be generally identified as hc−hm, however it is defined as an absolute value of the difference. Therefore, it will be appreciated that average difference in height may be calculated as hm-hc when the height of the body **301** at the midpoint of the edge **314** is greater than the height at the corner **313**. More particularly, the average difference in height can be calculated based upon a plurality of shaped abrasive particles from a suitable sample size. The heights hc and hm of the particles can be measured using a STIL (Sciences et Techniques Industrielles de la Lumiere—France) Micro Measure 3D Surface Profilometer (white light (LED) chromatic aberration technique) and the average difference in height can be calculated based on the average values of hc and hm from the sample.

As illustrated in FIG. **3**B, in one particular embodiment, the body **301** of the shaped abrasive particle **300** may have an average difference in height at different locations at the body **301**. The body **301** can have an average difference in height, which can be the absolute value of [hc−hm] between the first corner height (hc) and the second midpoint height (hm) that is at least about 20 microns. It will be appreciated that average difference in height may be calculated as hm-hc when the height of the body **301** at a midpoint of the edge is greater than the height at an opposite corner. In other instances, the average difference in height [hc−hm] can be at least about 25 microns, at least about 30 microns, at least about 36 microns, at least about 40 microns, at least about 60 microns, such as at least about 65 microns, at least about 70 microns, at least about 75 microns, at least about 80 microns, at least about 90 microns, or even at least about 100 microns. In one non-limiting embodiment, the average difference in height can be not greater than about 300 microns, such as not greater than about 250 microns, not greater than about 220 microns, or even not greater than about 180 microns. It will be appreciated that the average difference in height can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the average difference in height can be based upon an average value of hc. For example, the average height of the body **301** at the corners (Ahc) can be calculated by measuring the height of the body **301** at all corners and averaging the values, and may be distinct from a single value of height at one corner (hc). Accordingly, the average difference in height may be given by the absolute value of the equation [Ahc−hi]. Furthermore, it will be appreciated that the average difference in height can be calculated using a median interior height (Mhi) calculated from a suitable sample size from a batch of shaped abrasive particles and an average height at the corners for all particles in the sample size. Accordingly, the average difference in height may be given by the absolute value of the equation [Ahc-Mhi].

In particular instances, the body **301** can be formed to have a primary aspect ratio, which is a ratio expressed as width:length, having a value of at least 1:1. In other instances, the body **301** can be formed such that the primary aspect ratio (w:l) is at least about 1.5:1, such as at least about 2:1, at least about 4:1, or even at least about 5:1. Still, in other instances, the abrasive particle **300** can be formed such that the body **301** has a primary aspect ratio that is not greater than about 10:1, such as not greater than 9:1, not greater than about 8:1, or even not greater than about 5:1. It will be appreciated that the body **301** can have a primary aspect ratio within a range between any of the ratios noted above. Furthermore, it will be appreciated that reference herein to a height can be reference to the maximum height measurable of the abrasive particle **300**. It will be described later that the abrasive particle **300** may have different heights at different positions within the body **301** of the abrasive particle **300**.

In addition to the primary aspect ratio, the abrasive particle **300** can be formed such that the body **301** comprises a secondary aspect ratio, which can be defined as a ratio of length:height, wherein the height is an interior median height (Mhi). In certain instances, the secondary aspect ratio can be at least about 1:1, such as at least about 2:1, at least about 4:1, or even at least about 5:1. Still, in other instances, the abrasive particle **300** can be formed such that the body **301** has a secondary aspect ratio that is not greater than about 1:3, such as not greater than 1:2, or even not greater than about 1:1. It will be appreciated that the body **301** can have a secondary aspect ratio within a range between any of the ratios noted above, such as within a range between about 5:1 and about 1:1.

In accordance with another embodiment, the abrasive particle **300** can be formed such that the body **301** comprises a tertiary aspect ratio, defined by the ratio width:height, wherein the height is an interior median height (Mhi). The tertiary aspect ratio of the body **301** can be can be at least about 1:1, such as at least about 2:1, at least about 4:1, at least about 5:1, or even at least about 6:1. Still, in other instances, the abrasive particle **300** can be formed such that the body **301** has a tertiary aspect ratio that is not greater than about 3:1, such as not greater than 2:1, or even not greater than about 1:1. It will be appreciated that the body **301** can have a tertiary aspect ratio within a range between any of the ratios noted above, such as within a range between about 6:1 and about 1:1.

According to one embodiment, the body **301** of the shaped abrasive particle **300** can have particular dimensions, which may facilitate improved performance. For example, in one instance, the body **301** can have an interior height (hi), which can be the smallest dimension of height of the body **301** as measured along a dimension between any corner and opposite midpoint edge on the body **301**. In particular instances, wherein the body **301** is a generally triangular two-dimensional shape, the interior height (hi) may be the smallest dimension of height (i.e., measure between the bottom surface **304** and the upper surface **305**) of the body **301** for three measurements taken between each of the three corners and the opposite midpoint edges. The interior height (hi) of the body **301** of a shaped abrasive particle **300** is illustrated in FIG. **3**B. According to one embodiment, the interior height (hi) can be at least about 20% of the width (w). The height (hi) may be measured by sectioning or mounting and grinding the shaped abrasive particle **300** and viewing in a manner sufficient (e.g., light microscope or SEM) to determine the smallest height (hi) within the interior of the body **301**. In one particular embodiment, the height (hi) can be at least about 22% of the width, such as at least about 25%, at least about 30%, or even at least about 33%, of the width of the body **301**. For one non-limiting embodiment, the height (hi) of the body **301** can be not greater than about 80% of the width of the body **301**, such as not greater than about 76%, not greater than about 73%, not greater than about 70%, not greater than about 68% of the width, not greater than about 56% of the width, not greater than about 48% of the width, or even not greater than about 40% of the width. It will be appreciated that the height (hi) of the body **301** can be within a range between any of the above noted minimum and maximum percentages.

A batch of shaped abrasive particles, can be fabricated, wherein the median interior height value (Mhi) can be controlled, which may facilitate improved performance. In particular, the median internal height (hi) of a batch can be related to a median width of the shaped abrasive particles of the batch in the same manner as described above. Notably, the median interior height (Mhi) can be at least about 20% of the width, such as at least about 22%, at least about 25%, at least about 30%, or even at least about 33% of the median width of the shaped abrasive particles of the batch. For one non-limiting embodiment, the median interior height (Mhi) of the body **301** can be not greater than about 80%, such as not greater than about 76%, not greater than about 73%, not greater than about 70%, not greater than about 68% of the width, not greater than about 56% of the width, not greater than about 48% of the width, or even not greater than about 40% of the median width of the body **301**. It will be appreciated that the median interior height (Mhi) of the body **301** can be within a range between any of the above noted minimum and maximum percentages.

Furthermore, the batch of shaped abrasive particles may exhibit improved dimensional uniformity as measured by the standard deviation of a dimensional characteristic from a suitable sample size. According to one embodiment, the shaped abrasive particles can have an interior height variation (Vhi), which can be calculated as the standard deviation of interior height (hi) for a suitable sample size of particles from a batch. According to one embodiment, the interior height variation can be not greater than about 60 microns, such as not greater than about 58 microns, not greater than about 56 microns, or even not greater than about 54 microns. In one non-limiting embodiment, the interior height variation (Vhi) can be at least about 2 microns. It will be appreciated that the interior height variation of the body can be within a range between any of the above noted minimum and maximum values.

For another embodiment, the body **301** of the shaped abrasive particle **300** can have an interior height (hi) of at least about 400 microns. More particularly, the height may be at least about 450 microns, such as at least about 475 microns, or even at least about 500 microns. In still one non-limiting embodiment, the height of the body **301** can be not greater than about 3 mm, such as not greater than about 2 mm, not greater than about 1.5 mm, not greater than about 1 mm, or even not greater than about 800 microns. It will be appreciated that the height of the body **301** can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median interior height (Mhi) value for a batch of shaped abrasive particles.

For certain embodiments herein, the body **301** of the shaped abrasive particle **300** can have particular dimensions, including for example, a width≥length, a length≥height, and a width≥height. More particularly, the body **301** of the shaped abrasive particle **300** can have a width (w) of at least about 600 microns, such as at least about 700 microns, at least about 800 microns, or even at least about 900 microns. In one non-limiting instance, the body **301** can have a width of not greater than about 4 mm, such as not greater than about 3 mm, not greater than about 2.5 mm, or even not greater than about 2 mm. It will be appreciated that the width of the body **301** can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median width (Mw) for a batch of shaped abrasive particles.

The body **301** of the shaped abrasive particle **300** can have particular dimensions, including for example, a length (L middle or Lp) of at least about 0.4 mm, such as at least about 0.6 mm, at least about 0.8 mm, or even at least about 0.9 mm. Still, for at least one non-limiting embodiment, the body **301** can have a length of not greater than about 4 mm, such as not greater than about 3 mm, not greater than about 2.5 mm, or even not greater than about 2 mm. It will be appreciated that the length of the body **301** can be within a range between any of the above noted minimum and maximum values. Moreover, it will be appreciated that the above range of values can be representative of a median length (Ml), which may be more particularly, a median middle length (MLmiddle) or median profile length (MLp) for a batch of shaped abrasive particles.

The shaped abrasive particle **300** can have a body **301** having a particular amount of dishing, wherein the dishing value (d) can be defined as a ratio between an average height of the body **301** at the corners (Ahc) as compared to smallest dimension of height of the body **301** at the interior (hi). The average height of the body **301** at the corners (Ahc) can be calculated by measuring the height of the body **301** at all corners and averaging the values, and may be distinct from a single value of height at one corner (hc). The average height of the body **301** at the corners or at the interior can be measured using a STIL (Sciences et Techniques Industrielles de la Lumiere—France) Micro Measure 3D Surface Profilometer (white light (LED) chromatic aberration technique). Alternatively, the dishing may be based upon a median height of the particles at the corner (Mhc) calculated from a suitable sampling of particles from a batch. Likewise, the interior height (hi) can be a median interior height (Mhi) derived from a suitable sampling of shaped abrasive particles from a batch. According to one embodiment, the dishing value (d) can be not greater than about 2, such as not greater than about 1.9, not greater than about 1.8, not greater than about 1.7, not greater than about 1.6, not greater than about 1.5, or even not greater than about 1.2. Still, in at least one non-limiting embodiment, the dishing value (d) can be at least about 0.9, such as at least about 1.0. It will be appreciated that the dishing ratio can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above dishing values can be representative of a median dishing value (Md) for a batch of shaped abrasive particles.

The shaped abrasive particles of the embodiments herein, including for example, the body **301** of the particle of FIG. **3**A can have a bottom surface **304** defining a bottom area (A_b). In particular instances, the bottom surface **304** can be the largest surface of the body **301**. The bottom major surface **304** can have a surface area defined as the bottom area (A_b) that is different than the surface area of the upper major surface **303**. In one particular embodiment, the bottom major surface **304** can have a surface area defined as the bottom area (A_b) that is different than the surface area of the upper major surface **303**. In another embodiment, the bottom major surface **304** can have a surface area defined as the bottom area (A_b) that is less than the surface area of the upper major surface **303**.

Additionally, the body **301** can have a cross-sectional midpoint area (A_m) defining an area of a plane perpendicular to the bottom area (A_b) and extending through a midpoint **381** of the particle **300**. In certain instances, the body **301** can have an area ratio of bottom area to midpoint area (A_b/A_m) of not greater than about 6. In more particular instances, the area ratio can be not greater than about 5.5, such as not greater than about 5, not greater than about 4.5, not greater than about 4, not greater than about 3.5, or even not greater than about 3. Still, in one non-limiting embodiment, the area ratio may be at least about 1.1, such as at least about 1.3, or even at least about 1.8. It will be appreciated that the area ratio can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above area ratios can be representative of a median area ratio for a batch of shaped abrasive particles.

Furthermore the shaped abrasive particles of the embodiments herein including, for example, the particle of FIG. **3**B, can have a normalized height difference of not greater than about 0.3. The normalized height difference can be defined by the absolute value of the equation [(hc−hm)/(hi)]. In other embodiments, the normalized height difference can be not greater than about 0.26, such as not greater than about 0.22, or even not greater than about 0.19. Still, in one particular embodiment, the normalized height difference can be at least about 0.04, such as at least about 0.05, or even at least about 0.06. It will be appreciated that the normalized height difference can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above normalized height values can be representative of a median normalized height value for a batch of shaped abrasive particles.

In another instance, the body **301** can have a profile ratio of at least about 0.04, wherein the profile ratio is defined as a ratio of the average difference in height [hc−hm] to the length (Lmiddle) of the shaped abrasive particle **300**, defined as the absolute value of [(hc−hm)/(Lmiddle)]. It will be appreciated that the length (Lmiddle) of the body **301** can be the distance across the body **301** as illustrated in FIG. **3**B. Moreover, the length may be an average or median length calculated from a suitable sampling of particles from a batch of shaped abrasive particles as defined herein. According to a particular embodiment, the profile ratio can be at least about 0.05, at least about 0.06, at least about 0.07, at least about 0.08, or even at least about 0.09. Still, in one non-limiting embodiment, the profile ratio can be not greater than about 0.3, such as not greater than about 0.2, not greater than about 0.18, not greater than about 0.16, or even not greater than about 0.14. It will be appreciated that the profile ratio can be within a range between any of the minimum and maximum values noted above. Moreover, it will be appreciated that the above profile ratio can be representative of a median profile ratio for a batch of shaped abrasive particles.

According to another embodiment, the body **301** can have a particular rake angle, which may be defined as an angle between the bottom surface **304** and a side surface **305**, **306** or **307** of the body **301**. For example, the rake angle may be within a range between about 1° and about 80°. For other particles herein, the rake angle can be within a range between about 5° and 55°, such as between about 10° and about 50°, between about 15° and 50°, or even between about 20° and 50°. Formation of an abrasive particle having such a rake angle can improve the abrading capabilities of the abrasive particle **300**. Notably, the rake angle can be within a range between any two rake angles noted above.

According to another embodiment, the shaped abrasive particles herein including, for example, the particles of FIGS. **3**A and **3**B, can have an ellipsoidal region **317** in the upper surface **303** of the body **301**. The ellipsoidal region **317** can be defined by a trench region **318** that can extend around the upper surface **303** and define the ellipsoidal region **317**. The ellipsoidal region **317** can encompass the midpoint **381**. Moreover, it is thought that the ellipsoidal region **317** defined in the upper surface **303** can be an artifact of the forming process, and may be formed as a result of the stresses imposed on the mixture **101** during formation of the shaped abrasive particles according to the methods described herein.

The shaped abrasive particle **300** can be formed such that the body **301** includes a crystalline material, and more particularly, a polycrystalline material. Notably, the polycrystalline material can include abrasive grains. In one embodiment, the body **301** can be essentially free of an organic material, including for example, a binder. More particularly, the body **301** can consist essentially of a polycrystalline material.

In one aspect, the body **301** of the shaped abrasive particle **300** can be an agglomerate including a plurality of abrasive particles, grit, and/or grains bonded to each other to form the body **301** of the abrasive particle **300**. Suitable abrasive grains can include nitrides, oxides, carbides, borides, oxynitrides, oxyborides, diamond, and a combination thereof. In particular instances, the abrasive grains can include an oxide compound or complex, such as aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof. In one particular instance, the abrasive particle **300** is formed such that the abrasive grains forming the body **301** include alumina, and more particularly, may consist essentially of alumina. Moreover, in particular instances, the shaped abrasive particle **300** can be formed from a seeded sol-gel.

The abrasive grains (i.e., crystallites) contained within the body **301** may have an average grain size that is generally not greater than about 100 microns. In other embodiments, the average grain size can be less, such as not greater than about 80 microns, not greater than about 50 microns, not greater than about 30 microns, not greater than about 20 microns, not greater than about 10 microns, or even not greater than about 1 micron. Still, the average grain size of the abrasive grains contained within the body **301** can be at least about 0.01 microns, such as at least about 0.05 microns, such as at least about 0.08 microns, at least about 0.1 microns, or even at least about 0.5 microns. It will be appreciated that the abrasive grains can have an average grain size within a range between any of the minimum and maximum values noted above.

In accordance with certain embodiments, the abrasive particle **300** can be a composite article including at least two different types of grains within the body **301**. It will be appreciated that different types of grains are grains having different compositions with regard to each other. For example, the body **301** can be formed such that is includes at least two different types of grains, wherein the two different types of grains can be nitrides, oxides, carbides, borides, oxynitrides, oxyborides, diamond, and a combination thereof.

In accordance with an embodiment, the abrasive particle **300** can have an average particle size, as measured by the largest dimension measurable on the body **301**, of at least about 100 microns. In fact, the abrasive particle **300** can have an average particle size of at least about 150 microns, such as at least about 200 microns, at least about 300 microns, at least about 400 microns, at least about 500 microns, at least about 600 microns, at least about 700 microns, at least about 800 microns, or even at least about 900 microns. Still, the abrasive particle **300** can have an average particle size that is not greater than about 5 mm, such as not greater than about 3 mm, not greater than about 2 mm, or even not greater than about 1.5 mm. It will be appreciated that the abrasive particle **300** can have an average particle size within a range between any of the minimum and maximum values noted above.

The shaped abrasive particles of the embodiments herein can have a percent flashing that may facilitate improved performance. Notably, the flashing defines an area of the particle as viewed along one side, such as illustrated in FIG. **4**, wherein the flashing extends from a side surface of the body **301** within the boxes **402** and **403**. The flashing can represent tapered regions proximate to the upper surface **303** and bottom surface **304** of the body **301**. The flashing can be measured as the percentage of area of the body **301** along the side surface contained within a box extending between an innermost point of the side surface (e.g., **421**) and an outermost point (e.g., **422**) on the side surface of the body **301**. In one particular instance, the body **301** can have a particular content of flashing, which can be the percentage of area of the body **301** contained within the boxes **402** and **403** compared to the total area of the body **301** contained within boxes **402**, **403**, and **404**. According to one embodiment, the percent flashing (f) of the body **301** can be at least about 1%. In another embodiment, the percent flashing can be greater, such as at least about 2%, at least about 3%, at least about 5%, at least about 8%, at least about 10%, at least about 12%, such as at least about 15%, at least about 18%, or even at least about 20%. Still, in a non-limiting embodiment, the percent flashing of the body **301** can be controlled and may be not greater than about 45%, such as not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 18%, not greater than about 15%, not greater than about 12%, not greater than about 10%, not greater than about 8%, not greater than about 6%, or even not greater than about 4%. It will be appreciated that the percent flashing of the body **301** can be within a range between any of the above minimum and maximum percentages. Moreover, it will be appreciated that the above flashing percentages can be representative of an average flashing percentage or a median flashing percentage for a batch of shaped abrasive particles.

The percent flashing can be measured by mounting the shaped abrasive particle **300** on its side and viewing the body **301** at the side to generate a black and white image, such as illustrated in FIG. **4**. A suitable program for such includes ImageJ software. The percentage flashing can be calculated by determining the area of the body **301** in the boxes **402** and **403** compared to the total area of the body **301** as viewed at the side (total shaded area), including the area in the center **404** and within the boxes. Such a procedure can be completed for a suitable sampling of particles to generate average, median, and/or and standard deviation values.

A batch of shaped abrasive particles according to embodiments herein may exhibit improved dimensional uniformity as measured by the standard deviation of a dimensional characteristic from a suitable sample size. According to one embodiment, the shaped abrasive particles can have a flashing variation (Vf), which can be calculated as the standard deviation of flashing percentage (f) for a suitable sample size of particles from a batch. According to one embodiment, the flashing variation can be not greater than about 5.5%, such as not greater than about 5.3%, not greater than about 5%, or not greater than about 4.8%, not greater than about 4.6%, or even not greater than about 4.4%. In one non-limiting embodiment, the flashing variation (Vf) can be at least about

0.1%. It will be appreciated that the flashing variation can be within a range between any of the minimum and maximum percentages noted above.

The shaped abrasive particles of the embodiments herein can have a height (hi) and flashing multiplier value (hiF) of at least 4000, wherein hiF=(hi)(f), an "hi" represents a minimum interior height of the body **301** as described above and "f" represents the percent flashing. In one particular instance, the height and flashing multiplier value (hiF) of the body **301** can be greater, such as at least about 4500 micron %, at least about 5000 micron %, at least about 6000 micron %, at least about 7000 micron %, or even at least about 8000 micron %. Still, in one non-limiting embodiment, the height and flashing multiplier value can be not greater than about 45000 micron %, such as not greater than about 30000 micron %, not greater than about 25000 micron %, not greater than about 20000 micron %, or even not greater than about 18000 micron %. It will be appreciated that the height and flashing multiplier value of the body **301** can be within a range between any of the above minimum and maximum values. Moreover, it will be appreciated that the above multiplier value can be representative of a median multiplier value (MhiF) for a batch of shaped abrasive particles.

A Fixed Abrasive Article

After forming or sourcing the shaped abrasive particles, the particles can be combined with other materials to form a fixed abrasive article. Some suitable exemplary fixed abrasive articles can include bonded abrasive articles wherein the shaped abrasive particles are contained in a three dimensional matrix of bond material, and coated abrasive articles, wherein the shaped abrasive particles may be dispersed in a single-layer overlying a backing and bonded to the backing using one or more adhesive layers, the particles may be combined with a backing to form a coated abrasive article.

FIG. **5** includes a cross-sectional illustration of a coated abrasive article in accordance with an embodiment. In particular, coated abrasive article **500** can include a substrate **501** (i.e., a backing) and at least one adhesive layer overlying a surface of the substrate **501**. The adhesive layer can include a make coat **503** and/or a size coat **504**. The coated abrasive **500** can include abrasive particulate material **510**, which can include shaped abrasive particles **505** of the embodiments herein and a second type of abrasive particulate material **507** in the form of diluent abrasive particles having a random shape, which may not necessarily be shaped abrasive particles. The make coat **503** can be overlying the surface of the substrate **501** and surrounding at least a portion of the shaped abrasive particles **505** and second type of abrasive particulate material **507**. The size coat **504** can be overlying and bonded to the shaped abrasive particles **505** and second type of abrasive particulate material **507** and the make coat **503**.

According to one embodiment, the substrate **501** can include an organic material, inorganic material, and a combination thereof. In certain instances, the substrate **501** can include a woven material. However, the substrate **501** may be made of a non-woven material. Particularly suitable substrate materials can include organic materials, including polymers, and particularly, polyester, polyurethane, polypropylene, polyimides such as KAPTON from DuPont, paper. Some suitable inorganic materials can include metals, metal alloys, and particularly, foils of copper, aluminum, steel, and a combination thereof.

A polymer formulation may be used to form any of a variety of layers of the abrasive article such as, for example, a frontfill, a pre-size, the make coat, the size coat, and/or a supersize coat. When used to form the frontfill, the polymer formulation generally includes a polymer resin, fibrillated fibers (preferably in the form of pulp), filler material, and other optional additives. Suitable formulations for some frontfill embodiments can include material such as a phenolic resin, wollastonite filler, defoamer, surfactant, a fibrillated fiber, and a balance of water. Suitable polymeric resin materials include curable resins selected from thermally curable resins including phenolic resins, urea/formaldehyde resins, phenolic/latex resins, as well as combinations of such resins. Other suitable polymeric resin materials may also include radiation curable resins, such as those resins curable using electron beam, UV radiation, or visible light, such as epoxy resins, acrylated oligomers of acrylated epoxy resins, polyester resins, acrylated urethanes and polyester acrylates and acrylated monomers including monoacrylated, multiacrylated monomers. The formulation can also comprise a nonreactive thermoplastic resin binder which can enhance the self-sharpening characteristics of the deposited abrasive particles by enhancing the erodability. Examples of such thermoplastic resin include polypropylene glycol, polyethylene glycol, and polyoxypropylene-polyoxyethene block copolymer, etc. Use of a frontfill on the substrate **501** can improve the uniformity of the surface, for suitable application of the make coat **503** and improved application and orientation of shaped abrasive particles **505** in a predetermined orientation.

The make coat **503** can be applied to the surface of the substrate **501** in a single process, or alternatively, the abrasive particulate material **510** can be combined with a make coat **503** material and applied as a mixture to the surface of the substrate **501**. Suitable materials of the make coat **503** can include organic materials, particularly polymeric materials, including for example, polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and mixtures thereof. In one embodiment, the make coat **503** can include a polyester resin. The coated substrate can then be heated in order to cure the resin and the abrasive particulate material to the substrate. In general, the coated substrate **501** can be heated to a temperature of between about 100° C. to less than about 250° C. during this curing process.

The abrasive particulate material **510** can include shaped abrasive particles **505** according to embodiments herein. In particular instances, the abrasive particulate material **510** may include different types of shaped abrasive particles **505**. The different types of shaped abrasive particles can differ from each other in composition, in two-dimensional shape, in three-dimensional shape, in size, and a combination thereof as described in the embodiments herein. As illustrated, the coated abrasive **500** can include a shaped abrasive particle **505** having a generally triangular two-dimensional shape.

The other type of abrasive particles **507** can be diluent particles different than the shaped abrasive particles **505**. For example, the diluent particles can differ from the shaped abrasive particles **505** in composition, in two-dimensional shape, in three-dimensional shape, in size, and a combination thereof. For example, the abrasive particles **507** can represent conventional, crushed abrasive grit having random shapes. The abrasive particles **507** may have a median particle size less than the median particle size of the shaped abrasive particles **505**.

After sufficiently forming the make coat **503** with the abrasive particulate material **510**, the size coat **504** can be formed to overlie and bond the abrasive particulate material **510** in place. The size coat **504** can include an organic material, may be made essentially of a polymeric material, and notably, can use polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and mixtures thereof.

According to one embodiment, the shaped abrasive particles **505** herein can be oriented in a predetermined orientation relative to each other and the substrate **501**. While not completely understood, it is thought that one or a combination of dimensional features may be responsible for improved orientation of the shaped abrasive particles **505**. According to one embodiment, the shaped abrasive particles **505** can be oriented in a flat orientation relative to the substrate **501**, such as that shown in FIG. **5**. In the flat orientation, the bottom surface **304** of the shaped abrasive particles can be closest to a surface of the substrate **501** (i.e., the backing) and the upper surface **303** of the shaped abrasive particles **505** can be directed away from the substrate **501** and configured to conduct initial engagement with a workpiece.

According to another embodiment, the shaped abrasive particles **505** can be placed on a substrate **501** in a predetermined side orientation, such as that shown in FIG. **6**. In particular instances, a majority of the shaped abrasive particles **505** of the total content of shaped abrasive particles **505** on the abrasive article **500** can have a predetermined and side orientation. In the side orientation, the bottom surface **304** of the shaped abrasive particles **505** can be spaced away and angled relative to the surface of the substrate **501**. In particular instances, the bottom surface **304** can form an obtuse angle (B) relative to the surface of the substrate **501**. Moreover, the upper surface **303** is spaced away and angled relative to the surface of the substrate **501**, which in particular instances, may define a generally acute angle (A). In a side orientation, a side surface (**305**, **306**, or **307**) can be closest to the surface of the substrate **501**, and more particularly, may be in direct contact with a surface of the substrate **501**.

For certain other abrasive articles herein, at least about 55% of the plurality of shaped abrasive particles **505** on the abrasive article **500** can have a predetermined side orientation. Still, the percentage may be greater, such as at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 77%, at least about 80%, at least about 81%, or even at least about 82%. And for one non-limiting embodiment, an abrasive article **500** may be formed using the shaped abrasive particles **505** herein, wherein not greater than about 99% of the total content of shaped abrasive particles have a predetermined side orientation.

To determine the percentage of particles in a predetermined orientation, a 2D microfocus x-ray image of the abrasive article **500** is obtained using a CT scan machine run in the conditions of Table 1 below. The X-ray 2D imaging was conducted on RB214 with Quality Assurance software. A specimen mounting fixture utilizes a plastic frame with a 4"×4" window and an 00.5" solid metallic rod, the top part of which is half flattened with two screws to fix the frame. Prior to imaging, a specimen was clipped over one side of the frame where the screw heads were faced with the incidence direction of the X-rays. Then five regions within the 4"×4" window area are selected for imaging at 120 kV/80 μA. Each 2D projection was recorded with the X-ray off-set/gain corrections and at a magnification of 15 times.

TABLE 1

Voltage (kV)	Current (μA)	Magnification	Field of view per image (mm × mm)	Exposure time
120	80	15X	16.2 × 13.0	500 ms/2.0 fps

The image is then imported and analyzed using the ImageJ program, wherein different orientations are assigned values according to Table 2 below. FIG. **13** includes images representative of portions of a coated abrasive according to an embodiment and used to analyze the orientation of shaped abrasive particles on the backing.

TABLE 2

Cell marker type	Comments
1	Grains on the perimeter of the image, partially exposed—standing up
2	Grains on the perimeter of the image, partially exposed—down
3	Grains on the image, completely exposed—standing vertical
4	Grains on the image, completely exposed—down
5	Grains on the image, completely exposed—standing slanted (between standing vertical and down)

Three calculations are then performed as provided below in Table 3. After conducting the calculations, the percentage of grains in a particular orientation (e.g., side orientation) per square centimeter can be derived.

TABLE 3

5) Parameter	Protocol*
% grains up	((0.5 × 1) + 3 + 5)/(1 + 2 + 3 + 4 + 5)
Total # of grains per cm^2	(1 + 2 + 3 + 4 + 5)
# of grains up per cm^2	(% grains up × Total # of grains per cm^2

*These are all normalized with respect to the representative area of the image.
+A scale factor of 0.5 was applied to account for the fact that they are not completely present in the image.

Furthermore, the abrasive articles made with the shaped abrasive particles can utilize various contents of the shaped abrasive particles. For example, the abrasive articles can be coated abrasive articles including a single layer of the shaped abrasive particles in an open-coat configuration or a closed-coat configuration. For example, the plurality of shaped abrasive particles can define an open-coat abrasive product having a coating density of shaped abrasive particles of not greater than about 70 particles/cm^2. In other instances, the open-coat density of shaped abrasive particle per square centimeter of abrasive article may be not greater than about 65 particles/cm^2, such as not greater than about 60 particles/cm^2, not greater than about 55 particles/cm^2, or even not greater than about 50 particles/cm^2. Still, in one non-limiting embodiment, the density of the open-coat coated abrasive using the shaped abrasive particle herein can be at least about 5 particles/cm^2, or even at least about 10 particles/cm^2. It will be appreciated that the open-coat density of the coated abrasive article can be within a range between any of the above minimum and maximum values.

In an alternative embodiment, the plurality of shaped abrasive particles can define a closed-coat abrasive product having a coating density of shaped abrasive particles of at least about 75 particles/cm^2, such as at least about 80 particles/cm^2, at least about 85 particles/cm^2, at least about 90 particles/cm^2, at least about 100 particles/cm^2. Still, in one non-limiting embodiment, the closed-coat density of the coated abrasive using the shaped abrasive particle herein can be not greater than about 500 particles/cm^2. It will be appreciated that the closed coat density of the coated abrasive article can be within a range between any of the above minimum and maximum values.

In certain instances, the abrasive article can have an open-coat density of a coating not greater than about 50% of abrasive particle covering the exterior abrasive surface of the article. In other embodiments, the percentage coating of the abrasive particles relative to the total area of the abrasive surface can be not greater than about 40%, not greater than about 30%, not greater than about 25%, or even not greater than about 20%. Still, in one non-limiting embodiment, the percentage coating of the abrasive particles relative to the total area of the abrasive surface can be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, or even at least about 40%. It will be appreciated that the percent coverage of shaped abrasive particles for the total area of abrasive surface can be within a range between any of the above minimum and maximum values.

Some abrasive articles may have a particular content of abrasive particles for a length (e.g., ream) of the backing or the substrate **501**. For example, in one embodiment, the abrasive article may utilize a normalized weight of shaped abrasive particles of at least about 20 lbs/ream, such as at least about 25 lbs/ream, or even at least about 30 lbs/ream. Still, in one non-limiting embodiment, the abrasive articles can include a normalized weight of shaped abrasive particles of not greater than about 60 lbs/ream, such as not greater than about 50 lbs/ream, or even not greater than about 45 lbs/ream. It will be appreciated that the abrasive articles of the embodiments herein can utilize a normalized weight of shaped abrasive particle within a range between any of the above minimum and maximum values.

The plurality of shaped abrasive particles on an abrasive article as described herein can define a first portion of a batch of abrasive particles, and the features described in the embodiments herein can represent features that are present in at least a first portion of a batch of shaped abrasive particles. Moreover, according to an embodiment, control of one or more process parameters as already described herein also can control the prevalence of one or more features of the shaped abrasive particles of the embodiments herein. The provision of one or more features of any shaped abrasive particle of a batch may facilitate alternative or improved deployment of the particles in an abrasive article and may further facilitate improved performance or use of the abrasive article. The batch may also include a second portion of abrasive particles. The second portion of abrasive particles can include diluent particles.

In accordance with one aspect of the embodiments herein, a fixed abrasive article can include a blend of abrasive particles. The blend of abrasive particles can include a first type of shaped abrasive particle and a second type of shaped abrasive particle. In particular instances, the first type of shaped abrasive particle can be defined by a first height (h**1**). It will be appreciated that reference to the first height can include any height dimension identified in the embodiments herein, including for example, but not limited to, a median interior height (Mhi) of the first type of shaped abrasive particle. Moreover, the second type of shaped abrasive particle can be defined by a second height (h**2**). It will be appreciated that reference to the second height can include any height dimension identified in the embodiments herein, including for example, but not limited to, a median interior height (Mhi) of the second type of shaped abrasive particle.

In accordance with one embodiment, the second type of shaped abrasive particle can have a second height (h**2**) that is less than the first height (h**1**). More particularly, in certain instances, the blend of abrasive particles can have a height ratio (h**2**/h**1**) that can describe the second height (h**2**) of the second type of shaped abrasive particle of the blend divided by the first height (h**1**) of the first type of shaped abrasive particle of the blend. Certain height ratios of the blend may improve performance of the abrasive article. For at least one embodiment, the height ratio (h**2**/h**1**) can be not greater than about 0.98. In other instances, the height ratio (h**2**/h**1**) can be not greater than about 0.95, such as not greater than about 0.93, not greater than about 0.90, not greater than about 0.88, not greater than about 0.85, or even not greater than about 0.83. Still, in another non-limiting embodiment, the height ratio (h**2**/h**1**) can be at least about 0.05, such as at least about 0.08, at least about 0.1, at least about 0.12, at least about 0.15, at least about 0.18, at least about 0.2, at least about 0.22, at least about 0.25, at least about 0.28, at least about 0.3, at least about 0.32, at least about 0.35, at least about 0.4, at least about 0.45, at least about 0.5, at least about 0.55, at least about 0.6, or even at least about 0.65. It will be appreciated that the height ratio (h**2**/h**1**) of the blend including the first type of shaped abrasive particle and the second type of shaped abrasive particle can be within a range between any of the minimum and maximum values noted above.

In certain instances, the blend of abrasive particles may define a particular height difference (h**1**−h**2**) between the first height and the second height that may facilitate improved performance of the fixed abrasive article. As indicated, the height difference may define a numerical value of a difference between the second height (h**2**) subtracted from the first height (h**1**). For example, the blend may have a height difference (h**1**−h**2**) of at least about 1 micron. In accordance with another embodiment, the height difference (h**1**−h**2**) can be at least about 5 microns. In other instances, the height difference may be greater, such as at least about 10 microns, at least about 15 microns, at least about 20 microns, at least about 25 microns, at least about 30 microns, at least about 35 microns, at least about 40 microns, at least about 50 microns, at least about 60 microns, at least about 70 microns, or even at least about 80 microns. Still, in one non-limiting embodiment, the height difference (h**1**−h**2**) may be not greater than about 2 mm, such as not greater than about 1 mm, not greater than about 800 microns, or even not greater than about 500 microns. It will be appreciated that the height difference (h**1**−h**2**) may be within a range between any of the minimum and maximum values noted above.

As described herein, the shaped abrasive particles of the embodiments herein may have a body defined by a length, width, and height. In accordance with an embodiment, the first type of shaped abrasive particle may have a first length, and a second type of shaped abrasive particle may have a second length. Moreover, the blend of abrasive particles may have a length ratio (l**2**/l**1**) that can describe the second length (l**2**) of the second type of shaped abrasive particle of the blend divided by the first length (l**1**) of the first type of shaped abrasive particle of the blend. Certain length ratios of the blend may facilitate improved performance of the abrasive article. Accordingly, in certain instances, the first type of shaped abrasive particle may have a first length that is different than the second length corresponding to the second type of shaped abrasive particle. However, it will be appreciated that that the first length of the first type of shaped abrasive particle can be substantially the same as the second length of the second type of shaped abrasive particle.

In at least one embodiment, the length ratio (l2/l1) can be at least about 0.05, such as at least about 0.08, at least about 0.1, at least about 0.12, at least about 0.15, at least about 0.18, at least about 0.2, at least about 0.22, at least about 0.25, at least about 0.28, at least about 0.3, at least about 0.32, at least about 0.35, at least about 0.4, at least about 0.45, at least about 0.5, at least about 0.55, at least about 0.6, at least about 0.65, at least about 0.7, at least about 0.75, at least about 0.8, at least about 0.9, or even at least about 0.95. Still, in one non-limiting embodiment, the length ratio (l2/l1) may be not greater than about 10, such as, not greater than about 8, not greater than about 6, not greater than about 5, not greater than about 4, not greater than about 3, not greater than about 2, not greater than about 1.8, not greater than about 1.5, or even not greater than about 1.2. It will be appreciated that the length ratio (l2/l1) may be within a range between any of the minimum and maximum values noted above.

Furthermore, the blend of abrasive particles may define a particular length difference (l1−l2), which can define a difference in the first length of the first type of shaped abrasive particle of the blend relative to the second length of the second type of shaped abrasive particle of the blend, and which may facilitate improved performance of the abrasive article. For example, in one embodiment, the length difference (l1−l2) may be not greater than about 2 mm, such as not greater than about 1 mm, not greater than about 800 microns, not greater than about 500 microns, not greater than about 300 microns, not greater than about 100 microns, or even not greater than about 50 microns. Still, in one non-limiting embodiment, the length difference (l1−l2) may be at least about 1 micron, such as at least about 5 microns, or even at least about 10 microns. It will be appreciated that the length difference (l1−l2) may be within a range between any of the minimum and maximum values noted above.

As noted herein, the first type of shaped abrasive particle may have a body defining a first width (w1). Moreover, the second type of shaped abrasive particle may have a body defining a second width (w2). Furthermore, the blend of abrasive particles may have a width ratio (w2/w1) that can describe the second width (w2) of the second type of shaped abrasive particle of the blend divided by the first width (w1) of the first type of shaped abrasive particle of the blend. Certain width ratios of the blend may facilitate improved performance of the abrasive article. Accordingly, in certain instances, the first type of shaped abrasive particle may have a first width that is different than the second width corresponding to the second type of shaped abrasive particle. However, it will be appreciated that that the first width of the first type of shaped abrasive particle can be substantially the same as the second width of the second type of shaped abrasive particle.

In one particular embodiment, the width ratio (w2/w1) may be at least about 0.08, such as at least about 0.1, at least about 0.12, at least about 0.15, at least about 0.18, at least about 0.2, at least about 0.22, at least about 0.25, at least about 0.28, at least about 0.3, at least about 0.32, at least about 0.35, at least about 0.4, at least about 0.45, at least about 0.5, at least about 0.55, at least about 0.6, at least about 0.65, at least about 0.7, at least about 0.75, at least about 0.8, at least about 0.9, or even at least about 0.95. Still, in another non-limiting embodiment, the width ratio (w2/w1) may be not greater than about 10, such as not greater than about 8, not greater than about 6, not greater than about 5, not greater than about 4, not greater than about 3, not greater than about 2, not greater than about 1.8, not greater than about 1.5, or even not greater than about 1.2. It will be appreciated that the width ratio (w2/w1) may be within a range between any of the minimum and maximum values noted above.

Moreover, the blend of abrasive particles may have a width difference (w1−w2) that may define a difference in width between the first type of shaped abrasive particle of the blend and the width of the second type of shaped abrasive particle of the blend, and which may facilitate improved performance of the abrasive article. In at least one embodiment, the width difference (w1−w2) may be not greater than about 2 mm, such as not greater than about 1 mm, not greater than about 800 microns, not greater than about 500 microns, not greater about 300 microns, not greater than about 100 microns, or even not greater than about 50 microns. Still, in at least one non-limiting embodiment, the width difference (w1−w2) can be at least about 1 micron, such as at least about 5 microns, or even at least about 10 microns. It will be appreciated that the width difference can be within a range between any of the minimum and maximum values noted above.

In accordance with another aspect, the blend of abrasive particles can include a first type of shaped abrasive particle present in a first content (C1), which may be expressed as a percentage (e.g., a weight percent) of the first type of shaped abrasive particles as compared to the total content of particles of the blend. Furthermore, the blend of abrasive particles may include a second content (C2) of the second type of shaped abrasive particles, expressed as a percentage (e.g., a weight percent) of the second type of shaped abrasive particles relative to the total weight of the blend. In at least one embodiment, the first content can be different than the second content. More particularly, in at least one embodiment, the first content can be less than the second content.

For example, in certain instances, the blend can be formed such that the first content (C1) can be not greater than about 90% of the total content of the blend. In another embodiment, the first content may be less, such as not greater than about 85%, not greater than about 80%, not greater than about 75%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 15%, not greater than about 10%, or even not greater than about 5%. Still, in one non-limiting embodiment, the first content of the first type of shaped abrasive particles may be present in at least about 1% of the total content of abrasive particles of the blend. In yet other instances, the first content (C1) may be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, or even at least about 95%. It will be appreciated that the first content (C1) may be present within a range between any of the minimum and maximum percentages noted above.

The blend of abrasive particles may include a particular content of the second type of shaped abrasive particle. For example, the second content (C2) may be not greater than about 98% of the total content of the blend. In other embodiments, the second content may be not greater than about 95%, such as not greater than about 90%, not greater than about 85%, not greater than about 80%, not greater than about 75%, not greater than about 70%, not greater than about 65%, not greater than about 60%, not greater than about 55%, not greater than about 50%, not greater than about 45%, not greater than about 40%, not greater than about 35%, not greater than about 30%, not greater than about 25%, not greater than about 20%, not greater than about 15%, not greater than about 10%, or even not greater than about 5%. Still, in one non-limiting embodiment, the second content (C**2**) may be present in an amount of at least about 1% of the total content of the blend. For example, the second content may be at least about 5%, such as at least about 10%, at least about 15%, at least about 20%, at least about 25%, at least about 30%, at least about 35%, at least about 40%, at least about 45%, at least about 50%, at least about 55%, at least about 60%, at least about 65%, at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, or even at least about 95%. It will be appreciated that the second content (C**2**) can be within a range between any of the minimum and maximum percentages noted above.

In accordance with another embodiment, the blend of abrasive particles may have a blend ratio (C**1**/C**2**) that may define a ratio between the first content (C**1**) and the second content (C**2**). For example, in one embodiment, the blend ratio (C**1**/C**2**) may be not greater than about 10. In yet another embodiment, the blend ratio (C**1**/C**2**) may be not greater than about 8, such as not greater than about 6, not greater than about 5, not greater than about 4, not greater than about 3, not greater than about 2, not greater than about 1.8, not greater than about 1.5, not greater than about 1.2, not greater than about 1, not greater than about 0.9, not greater than about 0.8, not greater than about 0.7, not greater than about 0.6, not greater than about 0.5, not greater than about 0.4, not greater than about 0.3, or even not greater than about 0.2. Still, in another non-limiting embodiment, the blend ratio (C**1**/C**2**) may be at least about 0.1, such as at least about 0.15, at least about 0.2, at least about 0.22, at least about 0.25, at least about 0.28, at least about 0.3, at least about 0.32, at least about 0.3, at least about 0.4, at least about 0.45, at least about 0.5, at least about 0.55, at least about 0.6, at least about 0.65, at least about 0.7, at least about 0.75, at least about 0.8, at least about 0.9, at least about 0.95, at least about 1, at least about 1.5, at least about 2, at least about 3, at least about 4, or even at least about 5. It will be appreciated that the blend ratio (C**1**/C**2**) may be within a range between any of the minimum and maximum values noted above.

In at least one embodiment, the blend of abrasive particles can include a majority content of shaped abrasive particles. That is, the blend can be formed primarily of shaped abrasive particles, including, but not limited to, a first type of shaped abrasive particle and a second type of shaped abrasive particle. In at least one particular embodiment, the blend of abrasive particles can consist essentially of the first type of shaped abrasive particle and the second type of shaped abrasive particle. However, in other non-limiting embodiments, the blend may include other types of abrasive particles. For example, the blend may include a third type of abrasive particle that may include a a conventional abrasive particle or a shaped abrasive particle. The third type of abrasive particle may include a diluent type of abrasive particle having an irregular shape, which may be achieved through conventional crushing and comminution techniques.

For at least one aspect, a fixed abrasive article according to an embodiment can include a blend of abrasive particles including a first type of shaped abrasive particle and a second type of shaped abrasive particle, wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11 in^3. The stainless steel lifespan of a fixed abrasive article can be determined according to the standard stainless steel grinding characterization test as defined herein. In one embodiment, the fixed abrasive article can have a stainless steel lifespan of at least about 11.5 in^3, such as at least about 12 in^3. Still, in another non-limiting embodiment, the fixed abrasive article can have a stainless steel lifespan of not greater than about 25 in^3, such as not greater than about 20 in^3. It will be appreciated that a fixed abrasive article according to an embodiment can have a stainless steel lifespan within a range between and including any of the minimum and maximum values noted above.

According to another embodiment, the blend of abrasive particles can include a plurality of shaped abrasive particles and each of the shaped abrasive particles of the plurality may be arranged in a controlled orientation relative to a backing. Suitable exemplary controlled orientations can include at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation. In at least one embodiment, the plurality of shaped abrasive particles having a controlled orientation can include at least a portion of the first type of shaped abrasive particles of the blend, at least a portion of the second type of shaped abrasive particles of the blend, and a combination thereof. More particularly, the plurality of shaped abrasive particles having a controlled orientation can include all of the first type of shaped abrasive particles. In still another embodiment, the plurality of shaped abrasive particles arranged in a controlled orientation relative to the backing may include all of the second type of shaped abrasive particles within the blend of abrasive particles.

FIG. **7** includes a top view illustration of a portion of a coated abrasive article including shaped abrasive particles having controlled orientation. As illustrated, the coated abrasive article **700** includes a backing **701** that can be defined by a longitudinal axis **780** that extends along and defines a length of the backing **701** and a lateral axis **781** that extends along and defines a width of the backing **701**. In accordance with an embodiment, a shaped abrasive particle **702** can be located in a first, predetermined position **712** defined by a particular first lateral position relative to the lateral axis of **781** of the backing **701** and a first longitudinal position relative to the longitudinal axis **780** of the backing **701**. Furthermore, a shaped abrasive particle **703** may have a second, predetermined position **713** defined by a second lateral position relative to the lateral axis **781** of the backing **701**, and a first longitudinal position relative to the longitudinal axis **780** of the backing **701** that is substantially the same as the first longitudinal position of the shaped abrasive particle **702**. Notably, the shaped abrasive particles **702** and **703** may be spaced apart from each other by a lateral space **721**, defined as a smallest distance between the two adjacent shaped abrasive particles **702** and **703** as measured along a lateral plane **784** parallel to the lateral axis **781** of the backing **701**. In accordance with an embodiment, the lateral space **721** can be greater than zero, such that some distance exists between the shaped abrasive particles **702** and **703**. However, while not illustrated, it will be appreciated that the lateral space **721** can be zero, allowing for contact and even overlap between portions of adjacent shaped abrasive particle.

As further illustrated, the coated abrasive article **700** can include a shaped abrasive particle **704** located at a third, predetermined position **714** defined by a second longitudinal position relative to the longitudinal axis **780** of the backing **701** and also defined by a third lateral position relative to a lateral plane **785** parallel to the lateral axis **781** of the backing **701** and spaced apart from the lateral axis **784**. Further, as illustrated, a longitudinal space **723** may exist between the shaped abrasive particles **702** and **704**, which can be defined as a smallest distance between the two adjacent shaped abrasive particles **702** and **704** as measured in a direction parallel to the longitudinal axis **780**. In accordance with an embodiment, the longitudinal space **723** can be greater than zero. Still, while not illustrated, it will be appreciated that the longitudinal space **723** can be zero, such that the adjacent shaped abrasive particles are touching, or even overlapping each other.

FIG. **8**A includes a top view illustration of a portion of an abrasive article including shaped abrasive particles in accordance with an embodiment. As illustrated, the abrasive article **800** can include a shaped abrasive particle **802** overlying a backing **801** in a first position having a first rotational orientation relative to a lateral axis **781** defining the width of the backing **801**. In particular, the shaped abrasive particle **802** can have a predetermined rotational orientation defined by a first rotational angle between a lateral plane **884** parallel to the lateral axis **781** and a dimension of the shaped abrasive particle **802**. Notably, reference herein to a dimension of the shaped abrasive particle **802** can include reference to a bisecting axis **831** of the shaped abrasive particle **802**, such bisecting axis **831** extending through a center point **821** of the shaped abrasive particle **802** along a surface (e.g., a side or an edge) connected to (directly or indirectly) the backing **801**. Accordingly, in the context of a shaped abrasive particle positioned in a side orientation, (see, e.g., FIG. **6**), the bisecting axis **831** can extend through a center point **821** and in the direction of the width (w) of a side **833** closest to the surface of the backing **801**.

In certain embodiments, the predetermined rotational orientation of the shaped abrasive particle **802** can be defined by a predetermined rotational angle **841** that defines the smallest angle between the bisecting axis **831** and the lateral plane **884**, both of which extend through the center point **821** as viewed from the top down in FIG. **8**A. In accordance with an embodiment, the predetermined rotational angle **841**, and thus the predetermined rotational orientation, can be 0°. In other embodiments, the predetermined rotational angle defining the predetermined rotational orientation can be greater, such as at least about 2°, at least about 5°, at least about 10°, at least about 15°, at least about 20°, at least about 25°, at least about 30°, at least about 35°, at least about 40°, at least about 45°, at least about 50°, at least about 55°, at least about 60°, at least about 70°, at least about 80°, or even at least about 85°. Still, the predetermined rotational orientation as defined by the rotational angle **841** may be not greater than about 90°, such as not greater than about 85°, not greater than about 80°, not greater than about 75°, not greater than about 70°, not greater than about 65°, not greater than about 60°, such as not greater than about 55°, not greater than about 50°, not greater than about 45°, not greater than about 40°, not greater than about 35°, not greater than about 30°, not greater than about 25°, not greater than about 20°, such as not greater than about 15°, not greater than about 10°, or even not greater than about 5°. It will be appreciated that the predetermined rotational orientation can be within a range between any of the above minimum and maximum angles.

FIG. **8**B includes a perspective view illustration of a portion of the abrasive article **800** including the shaped abrasive particle **802** in accordance with an embodiment. As illustrated, the abrasive article **800** can include the shaped abrasive particle **802** overlying the backing **801** in a first position **812** such that the shaped abrasive particle **802** includes a first rotational orientation relative to the lateral axis **781** defining the width of the backing **801**. Certain aspects of the predetermined orientation of a shaped abrasive particle may be described by reference to a x, y, z three-dimensional axis as illustrated. For example, the predetermined longitudinal orientation of the shaped abrasive particle **802** may be described by reference to the position of the shaped abrasive particle **802** relative to the y-axis, which extends parallel to the longitudinal axis **780** of the backing **801**. Moreover, the predetermined lateral orientation of the shaped abrasive particle **802** may be described by reference to the position of the shaped abrasive particle on the x-axis, which extends parallel to the lateral axis **781** of the backing **801**. Furthermore, the predetermined rotational orientation of the shaped abrasive particle **802** may be defined with reference to a bisecting axis **831** that extends through the center point **821** of the side **833** of the shaped abrasive particle **802**. Notably, the side **833** of the shaped abrasive particle **802** may be connected either directly or indirectly to the backing **801**. In a particular embodiment, the bisecting axis **831** may form an angle with any suitable reference axis including, for example, the x-axis that extends parallel to the lateral axis **781**. The predetermined rotational orientation of the shaped abrasive particle **802** may be described as a rotational angle formed between the x-axis and the bisecting axis **831**, which rotational angle is depicted in FIG. **8**B as angle **841**. Notably, the controlled placement of a plurality of shaped abrasive particles on the backing of the abrasive article, which placement facilitates control of the predetermined orientation characteristics described herein, is a highly involved process that has not previously been contemplated or deployed in the industry.

FIG. **9** includes a perspective view illustration of a portion of an abrasive article including shaped abrasive particles having predetermined orientation characteristics relative to a grinding direction in accordance with an embodiment. In one embodiment, the abrasive article **900** can include a shaped abrasive particle **902** having a predetermined orientation relative to another shaped abrasive particle **903** and/or relative to a grinding direction **985**. The grinding direction **985** may be an intended direction of movement of the abrasive article relative to a workpiece in a material removal operation. In particular instances, the grinding direction **985** may be defined relative to the dimensions of the backing **901**. For example, in one embodiment, the grinding direction **985** may be substantially perpendicular to the lateral axis **981** of the backing and substantially parallel to the longitudinal axis **980** of the backing **901**. The predetermined orientation characteristics of the shaped abrasive particle **902** may define an initial contact surface of the shaped abrasive particle **902** with a workpiece. For example, the shaped abrasive particle **902** can include major surfaces **963** and **964** and side surfaces **965** and **966**, each of which can extend between the major surfaces **963** and **964**. The predetermined orientation characteristics of the shaped abrasive particle **902** can position the particle **902** such that the major surface **963** is configured to make initial contact with a workpiece before the other surfaces of the shaped abrasive particle **902** during a material removal operation. Such an orientation may be considered a major surface orientation relative to the grinding direction **985**. More particularly, the shaped abrasive particle **902** can have a bisecting axis **931** having a particular orientation relative to the grinding direction **985**. For example, as illustrated, the vector of the grinding direction **985** and the bisecting axis **931** are substantially perpendicular to each other. It will be appreciated that, just as any range of predetermined rotational orientations relative to the backing are contemplated for a shaped abrasive particle, any range of orientations of the shaped abrasive particles relative to the grinding direction **985** are contemplated and can be utilized.

The shaped abrasive particle **903** can have one or more different predetermined orientation characteristics as compared to the shaped abrasive particle **902** and the grinding direction **985**. As illustrated, the shaped abrasive particle **903** can include major surfaces **991** and **992**, each of which can be joined by side surfaces **971** and **972**. Moreover, as illustrated, the shaped abrasive particle **903** can have a bisecting axis **973** forming a particular angle relative to the vector of the grinding direction **985**. As illustrated, the bisecting axis **973** of the shaped abrasive particle **903** can have a substantially parallel orientation with the grinding direction **985** such that the angle between the bisecting axis **973** and the grinding direction **985** is essentially 0 degrees. Accordingly, the predetermined orientation characteristics of the shaped abrasive particle **903** facilitate initial contact of the side surface **972** with a workpiece before any of the other surfaces of the shaped abrasive particle **903**. Such an orientation of the shaped abrasive particle **903** may be considered a side surface orientation relative to the grinding direction **985**.

Still, in one non-limiting embodiment, it will be appreciated that an abrasive article can include one or more groups of shaped abrasive particles that can be arranged in one or more predetermined distributions relative to the backing, a grinding direction, and/or each other. For example, one or more groups of shaped abrasive particles, as described herein, can have a predetermined orientation relative to a grinding direction. Moreover, the abrasive articles herein can have one or more groups of shaped abrasive particles, each of the groups having a different predetermined orientation relative to a grinding direction. Utilization of groups of shaped abrasive particles having different predetermined orientations relative to a grinding direction can facilitate improved performance of the abrasive article.

FIG. **10** includes a top view illustration of a portion of an abrasive article in accordance with an embodiment. In particular, the abrasive article **1000** can include a first group **1001** including a plurality of shaped abrasive particles. As illustrated, the shaped abrasive particles can be arranged relative to each other one the backing **101** to define a predetermined distribution. More particularly, the predetermined distribution can be in the form of a pattern **1023** as viewed top-down, and more particularly defining a triangular shaped two-dimensional array. As further illustrated, the first group **1001** can be arranged on the abrasive article **1000** defining a predetermined macro-shape **1031** overlying the backing **101**. In accordance with an embodiment, the macro-shape **1031** can have a particular two-dimensional shape as viewed top-down. Some exemplary two-dimensional shapes can include polygons, ellipsoids, numerals, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, Arabic alphabet characters, Kanji characters, complex shapes, irregular shapes, designs, any a combination thereof. In particular instances, the formation of a group having a particular macro-shape may facilitate improved performance of the abrasive article.

As further illustrated, the abrasive article **1000** can include a group **1004** including a plurality of shaped abrasive particles which can be arranged on the surface of the backing **101** relative to each other to define a predetermined distribution. Notably, the predetermined distribution can include an arrangement of the plurality of the shaped abrasive particles that define a pattern **1024**, and more particularly, a generally quadrilateral pattern. As illustrated, the group **1004** can define a macro-shape **1034** on the surface of the abrasive article **1000**. In one embodiment, the macro-shape **1034** of the group **1004** can have a two-dimensional shape as viewed top down, including for example a polygonal shape, and more particularly, a generally quadrilateral (diamond) shape as viewed top down on the surface of the abrasive article **1000**. In the illustrated embodiment of FIG. **10**, the group **1001** can have a macro-shape **1031** that is substantially the same as the macro-shape **1034** of the group **1004**. However, it will be appreciated that in other embodiments, various different groups can be used on the surface of the abrasive article, and more particularly wherein each of the different groups has a different macro-shape relative to each other.

As further illustrated, the abrasive article can include groups **1001**, **1002**, **1003**, and **1004** which can be separated by channel regions **1021** and **1022** extending between the groups **1001-1004**. In particular instances, the channel regions **1021** and **1022** can be substantially free of shaped abrasive particles. Moreover, the channel regions **1021** and **1022** may be configured to move liquid between the groups **1001-1004** and further improve swarf removal and grinding performance of the abrasive article. Furthermore, in a certain embodiment, the abrasive article **1000** can include channel regions **1021** and **1022** extending between groups **1001-1004**, wherein the channel regions **1021** and **1022** can be patterned on the surface of the abrasive article **1000**. In particular instances, the channel regions **1021** and **1022** can represent a regular and repeating array of features extending along a surface of the abrasive article.

The fixed abrasive articles of the embodiments herein can be utilized in various material removal operations. For example, fixed abrasive articles herein can be used in methods of removing material from a workpiece by moving the fixed abrasive article relative to the workpiece. The relative movement between the fixed abrasive and the workpiece can facilitate removal of the material from the surface of the workpiece. Various workpieces can be modified using the fixed abrasive articles of the embodiments herein, including but not limited to, workpieces comprising inorganic materials, organic materials, and a combination thereof. In a particular embodiment, the workpiece may include a metal, such as a metal alloy. In one particular instance, the workpiece can consist essentially of a metal or metal alloy, such as stainless steel.

Item 1. A fixed abrasive article comprising:

a blend of abrasive particles comprising:

a first type of shaped abrasive particle comprising a first height (h**1**);

a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height.

Item 2. The fixed abrasive article of item 1, further comprising a height ratio (h**2**/h**1**) of not greater than about 0.98, wherein the height ratio (h**2**/h**1**) is not greater than about 0.95 or not greater than about 0.93 or not greater than about 0.90 or not greater than about 0.88 or not greater than about 0.85 or not greater than about 0.83.

Item 3. The fixed abrasive article of item 2, wherein the height ratio (h2/h1) is at least about 0.05 or at least about 0.08 or at least about 0.1 or at least about 0.12 or at least about 0.15 or at least about 0.18 or at least about 0.2 or at least about 0.22 or at least about 0.25 or at least about 0.28 or at least about 0.3 or at least about 0.32 or at least about 0.35 or at least about 0.4 or at least about 0.45 or at least about 0.5 or at least about 0.55 or at least about 0.6 or at least about 0.65.

Item 4. The fixed abrasive article of item 1, further comprising a height difference (h1−h2) of at least about 1 micron.

Item 5. The fixed abrasive article of item 4, wherein the height difference (h1−h2) is at least about 5 microns or at least about 10 microns or at least about 15 microns or at least about 20 microns or at least about 25 microns or at least about 30 microns or at least about 35 microns or at least about 40 microns or at least about 50 microns or at least about 60 microns or at least about 70 microns or at least about 80 microns.

Item 6. The fixed abrasive article of item 4, wherein the height difference (h1−h2) is not greater than about 2 mm or not greater than about 1 mm or not greater than about 800 microns or not greater than about 500 microns.

Item 7. The fixed abrasive article of item 1, wherein the first type of shaped abrasive particle comprises a first length (l1), and the second type of shaped abrasive particle comprises a second length (l2), and further comprising a length ratio (l1/l2) of at least about 0.05.

Item 8. The fixed abrasive article of item 7, wherein the length ratio (l1/l2) is at least about 0.08 or at least about 0.1 or at least about 0.12 or at least about 0.15 or at least about 0.18 or at least about 0.2 or at least about 0.22 or at least about 0.25 or at least about 0.28 or at least about 0.3 or at least about 0.32 or at least about 0.35 or at least about 0.4 or at least about 0.45 or at least about 0.5 or at least about 0.55 or at least about 0.6 or at least about 0.65 or at least about 0.7 or at least about 0.75 or at least about 0.8 or at least about 0.9 or at least about 0.95.

Item 9. The fixed abrasive article of item 7, wherein the length ratio (l1/l2) is not greater than about 10 or not greater than about 8 or not greater than about 6 or not greater than about 5 or not greater than about 4 or not greater than about 3 or not greater than about 2 or not greater than about 1.8 or not greater than about 1.5 or not greater than about 1.2.

Item 10. The fixed abrasive article of item 7, further comprising a length difference (L1−l2) of not greater than about 2 mm or not greater than about 1 mm or not greater than about 800 microns or not greater than about 500 microns or not greater than about 300 microns or not greater than about 100 microns or not greater than about 50 microns.

Item 11. The fixed abrasive article of item 10, wherein the length difference (L1−l2) can be at least about 1 micron or at least about 5 microns or at least about 10 microns.

Item 12. The fixed abrasive article of item 1, wherein the first type of shaped abrasive particle comprises a first width (w1), and the second type of shaped abrasive particle comprises a second width (w2), and further comprising a width ratio (w2/w1) of at least about 0.05.

Item 13. The fixed abrasive article of item 12, wherein the width ratio (w2/w1) is at least about 0.08 or at least about 0.1 or at least about 0.12 or at least about 0.15 or at least about 0.18 or at least about 0.2 or at least about 0.22 or at least about 0.25 or at least about 0.28 or at least about 0.3 or at least about 0.32 or at least about 0.35 or at least about 0.4 or at least about 0.45 or at least about 0.5 or at least about 0.55 or at least about 0.6 or at least about 0.65 or at least about 0.7 or at least about 0.75 or at least about 0.8 or at least about 0.9 or at least about 0.95.

Item 14. The fixed abrasive article of item 12, wherein the width ratio (w2/w1) is not greater than about 10 or not greater than about 8 or not greater than about 6 or not greater than about 5 or not greater than about 4 or not greater than about 3 or not greater than about 2 or not greater than about 1.8 or not greater than about 1.5 or not greater than about 1.2.

Item 15. The fixed abrasive article of item 12, further comprising a width difference (w1−w2) of not greater than about 2 mm or not greater than about 1 mm or not greater than about 800 microns or not greater than about 500 microns or not greater than about 300 microns or not greater than about 100 microns or not greater than about 50 microns.

Item 16. The fixed abrasive article of item 15, wherein the width difference (w1−w2) can be at least about 1 micron or at least about 5 microns or at least about 10 microns.

Item 17. The fixed abrasive article of item 1, wherein the first content is less than the second content.

Item 18. The fixed abrasive article of item 1, wherein the first content is not greater than about 90% of the total content of the blend or not greater than about 85% or not greater than about 80% or not greater than about 75% or not greater than about 70% or not greater than about 65% or not greater than about 60% or not greater than about 55% or not greater than about 50% or not greater than about 45% or not greater than about 40% or not greater than about 35% or not greater than about 30% or not greater than about 25% or not greater than about 20% or not greater than about 15% or not greater than about 10% or not greater than about 5%.

Item 19. The fixed abrasive article of item 1, wherein the first content is at least about 1% of the total content of the blend or at least about 5% or at least about 10% or at least about 15% or at least about 20% or at least about 25% or at least about 30% or at least about 35% or at least about 40% or at least about 45% or at least about 50% or at least about 55% or at least about 60% or at least about 65% or at least about 70% or at least about 75% or at least about 80% or at least about 85% or at least about 90% or at least about 95%.

Item 20. The fixed abrasive article of item 1, wherein the second content is not greater than about 98% of the total content of the blend or not greater than about 95% or not greater than about 90% or not greater than about 85% or not greater than about 80% or not greater than about 75% or not greater than about 70% or not greater than about 65% or not greater than about 60% or not greater than about 55% or not greater than about 50% or not greater than about 45% or not greater than about 40% or not greater than about 35% or not greater than about 30% or not greater than about 25% or not greater than about 20% or not greater than about 15% or not greater than about 10% or not greater than about 5%.

Item 21. The fixed abrasive article of item 1, wherein the second content is at least about 1% of the total content of the blend or at least about 5% or at least about 10% or at least about 15% or at least about 20% or at least about 25% or at least about 30% or at least about 35% or at least about 40% or at least about 45% or at least about 50% or at least about 55% or at least about 60% or at least about 65% or at least about 70% or at least about 75% or at least about 80% or at least about 85% or at least about 90% or at least about 95%.

Item 22. The fixed abrasive article of item 1, wherein the blend of abrasive particles comprises a first content (C1) of the first type of shaped abrasive particle, and a second content (C2) of the second type of shaped abrasive particle, and further comprising a blend ratio (C1/C2) of not greater than about 10.

Item 23. The fixed abrasive article of item 22, wherein the blend ratio (C1/C2) is not greater than about 8 or not greater than about 6 or not greater than about 5 or not greater than about 4 or not greater than about 3 or not greater than about 2 or not greater than about 1.8 or not greater than about 1.5 or not greater than about 1.2 or not greater than about 1 or not greater than about 0.9 or not greater than about 0.8 or not greater than about 0.7 or not greater than about 0.6 or not greater than about 0.5 or not greater than about 0.4 or not greater than about 0.3 or not greater than about 0.2.

Item 24. The fixed abrasive article of item 22, wherein the blend ratio (C1/C2) is at least about 0.1 or at least about 0.15 or at least about 0.2 or at least about 0.22 or at least about 0.25 or at least about 0.28 or at least about 0.3 or at least about 0.32 or at least about 0.35 or at least about 0.4 or at least about 0.45 or at least about 0.5 or at least about 0.55 or at least about 0.6 or at least about 0.65 or at least about 0.7 or at least about 0.75 or at least about 0.8 or at least about 0.9 or at least about 0.95 or at least about 1 or at least about 1.5 or at least about 2 or at least about 3 or at least about 4 or at least about 5.

Item 25. The fixed abrasive article of item 1, wherein the blend of abrasive particles includes a majority content of shaped abrasive particles.

Item 26. The fixed abrasive article of item 1, wherein the blend of abrasive particles consists essentially of the first type of shaped abrasive particle and the second type of shaped abrasive particle.

Item 27. The fixed abrasive article of item 1, wherein the blend further comprises a third type of abrasive particle, wherein the third type of abrasive particle comprises a shaped abrasive particle, wherein the third type of abrasive particle comprises a diluent type of abrasive particle, wherein the diluent type of abrasive particle comprises an irregular shape.

Item 28. The fixed abrasive article of item 1, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

Item 29. The fixed abrasive article of item 1, wherein the fixed abrasive article comprises a substrate, wherein the substrate comprises a backing, wherein the backing comprises a woven material, wherein the backing comprises a non-woven material, wherein the backing comprises an organic material, wherein the backing comprises a polymer, wherein the backing comprises a material selected from the group consisting of cloth, paper, film, fabric, fleeced fabric, vulcanized fiber, woven material, non-woven material, webbing, polymer, resin, phenolic resin, phenolic-latex resin, epoxy resin, polyester resin, urea formaldehyde resin, polyester, polyurethane, polypropylene, polyimides, and a combination thereof.

Item 30. The fixed abrasive article of item 29, wherein the backing comprises an additive selected from the group consisting of catalysts, coupling agents, curants, anti-static agents, suspending agents, anti-loading agents, lubricants, wetting agents, dyes, fillers, viscosity modifiers, dispersants, defoamers, and grinding agents.

Item 31. The fixed abrasive article of item 29, further comprising an adhesive layer overlying the backing, wherein the adhesive layer comprises a make coat, wherein the make coat overlies the backing, wherein the make coat is bonded directly to a portion of the backing, wherein the make coat comprises an organic material, wherein the make coat comprises a polymeric material, wherein the make coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 32. The fixed abrasive article of item 31, wherein the adhesive layer comprises a size coat, wherein the size coat overlies a portion of the plurality of shaped abrasive particles, wherein the size coat overlies a make coat, wherein the size coat is bonded directly to a portion of the plurality of shaped abrasive particles, wherein the size coat comprises an organic material, wherein the size coat comprises a polymeric material, wherein the size coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 33. The fixed abrasive article of item 1, wherein the blend of abrasive particles comprises a plurality of shaped abrasive particles, and wherein each shaped abrasive particle of the plurality of shaped abrasive particles is arranged in a controlled orientation relative to a backing, the controlled orientation including at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation.

Item 34. The fixed abrasive article of item 33, wherein the plurality of shaped abrasive particles includes at least a portion of the first type of shaped abrasive particles, wherein the plurality of shaped abrasive particles includes all of the first type of shaped abrasive particles.

Item 35. The fixed abrasive article of item 33, wherein the plurality of shaped abrasive particles includes at least a portion of the second type of shaped abrasive particles, wherein the plurality of shaped abrasive particles includes all of the second type of shaped abrasive particles.

Item 36. The fixed abrasive article of item 33, wherein a majority of the first type of abrasive particles are coupled to the backing in a side orientation, wherein at least about 55% of the shaped abrasive particles of the plurality of shaped abrasive particles are coupled to the backing in a side orientation or at least about 60% or at least about 65% or at least about 70% or at least about 75% or at least about 77% or at least about 80%, and not greater than about 99% or not greater than about 95% or not greater than about 90% or not greater than about 85%.

Item 37. The fixed abrasive article of item 33, wherein a majority of the second type of abrasive particles are coupled to the backing in a side orientation, wherein at least about 55% of the shaped abrasive particles of the plurality of shaped abrasive particles are coupled to the backing in a side orientation or at least about 60% or at least about 65% or at least about 70% or at least about 75% or at least about 77% or at least about 80%, and not greater than about 99% or not greater than about 95% or not greater than about 90% or not greater than about 85%.

Item 38. The fixed abrasive article of item 1, wherein the fixed abrasive article comprises a coated abrasive article having an open coat of the blend of shaped abrasive particles on a backing, wherein the open coat comprises a coating density of not greater than about 70 particles/cm^2 or not greater than about 65 particles/cm^2 or not greater than about 60 particles/cm^2 or not greater than about 55 particles/cm^2 or not greater than about 50 particles/cm^2, at least about 5 particles/cm^2 or at least about 10 particles/cm^2.

Item 39. The fixed abrasive article of item 1, wherein the fixed abrasive article comprises a coated abrasive article having a closed coat of the blend of shaped abrasive particles on a backing, wherein the closed coat comprises a coating density of at least about 75 particles/cm^2 or at least about 80 particles/cm^2 or at least about 85 particles/cm^2 or at least about 90 particles/cm^2 or at least about 100 particles/cm^2.

Item 40. The fixed abrasive article of item 1, wherein the first type of shaped abrasive particle comprises a body having a length (l), a width (w), and a height (hi), wherein the width≥length, the length≥height, and the width≥height.

Item 41. The fixed abrasive article of item 40, wherein the height (h) is at least about 20% of the width (w) or at least about 25% or at least about 30% or at least about 33%, and not greater than about 80% or not greater than about 76% or not greater than about 73% or not greater than about 70% or not greater than about 68% of the width or not greater than about 56% of the width or not greater than about 48% of the width or not greater than about 40% of the width.

Item 42. The fixed abrasive article of item 40, wherein the height (h) is at least about 400 microns or at least about 450 microns or at least about 475 microns or at least about 500 microns, and not greater than about 3 mm or not greater than about 2 mm or not greater than about 1.5 mm or not greater than about 1 mm or not greater than about 800 microns.

Item 43. The fixed abrasive article of item 40, wherein the width is at least about 600 microns or at least about 700 microns or at least about 800 microns or at least about 900 microns, and not greater than about 4 mm or not greater than about 3 mm or not greater than about 2.5 mm or not greater than about 2 mm.

Item 44. The fixed abrasive article of item 40, wherein the body comprises a percent flashing of at least about 1%, such as at least about 2% or at least about 3% or at least about 5% or at least about 8% or at least about 10% or at least about 12% or at least about 15% or at least about 18% or at least about 20%, and not greater than about 40% or not greater than about 35% or not greater than about 30% or not greater than about 25% or not greater than about 20% or not greater than about 18% or not greater than about 15% or not greater than about 12% or not greater than about 10% or not greater than about 8% or not greater than about 6% or not greater than about 4%.

Item 45. The fixed abrasive article of item 40, wherein the body comprises a dishing value (d) of not greater than about 2 or not greater than about 1.9 or not greater than about 1.8 or not greater than about 1.7 or not greater than about 1.6 or not greater than about 1.5 or not greater than about 1.2, and at least about 0.9 or at least about 1.0.

Item 46. The fixed abrasive article of item 40, wherein the body comprises a primary aspect ratio of width:length of at least about 1:1 and not greater than about 10:1.

Item 47. The fixed abrasive article of item 40, wherein the body comprises a secondary aspect ratio defined by a ratio of width:height within a range between about 5:1 and about 1:1.

Item 48. The fixed abrasive article of item 40, wherein the body comprises a tertiary aspect ratio defined by a ratio of length:height within a range between about 6:1 and about 1:1.

Item 49. The fixed abrasive article of item 40, wherein the body comprises a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a shape selected from the group consisting of triangular, quadrilateral, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, and a combination thereof, wherein the body comprises a two-dimensional shape as viewed in a plane defined by a length and a width of the body selected from the group consisting of ellipsoids, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, complex polygonal shapes, irregular shapes, and a combination thereof.

Item 50. The fixed abrasive article of item 40, wherein the body comprises a two-dimensional triangular shape as viewed in a plane defined by a length and width.

Item 51. The fixed abrasive article of item 40, wherein the body is essentially free of a binder, wherein the body is essentially free of an organic material.

Item 52. The fixed abrasive article of item 40, wherein the body comprises a polycrystalline material, wherein the polycrystalline material comprises grains, wherein the grains are selected from the group of materials consisting of nitrides, oxides, carbides, borides, oxynitrides, diamond, and a combination thereof, wherein the grains comprise an oxide selected from the group of oxides consisting of aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof, wherein the grains comprise alumina, wherein the grains consist essentially of alumina.

Item 53. The fixed abrasive article of item 40, wherein the body consists essentially of alumina.

Item 54. The fixed abrasive article of item 40, wherein the body is formed from a seeded sol gel.

Item 55. The fixed abrasive article of item 40, wherein the body comprises a polycrystalline material having an average grain size not greater than about 1 micron.

Item 56. The fixed abrasive article of item 40, wherein the body is a composite comprising at least about two different types of grains.

Item 57. The fixed abrasive article of item 40, wherein the body comprises an additive, wherein the additive comprises an oxide, wherein the additive comprises a metal element, wherein the additive comprises a rare-earth element.

Item 58. The fixed abrasive article of item 57, wherein the additive comprises a dopant material, wherein the dopant material includes an element selected from the group consisting of an alkali element, an alkaline earth element, a rare earth element, a transition metal element, and a combination thereof, wherein the dopant material comprises an element selected from the group consisting of hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof.

Item 59. The fixed abrasive article of item 1, wherein the first type of shaped abrasive particle comprises a body having a first major surface, a second major surface, and at least one side surface extending between the first major surface and the second major surface.

Item 60. The fixed abrasive article of item 59, wherein the first major surface defines an area different than the second major surface, wherein the first major surface defines an area greater than an area defined by the second major surface, wherein the first major surface defines an area less than an area defined by the second major surface.

Item 61. The fixed abrasive article of item 1, wherein the first type of shaped abrasive particle comprises a first abrasive characteristic selected from the group consisting of two-dimensional shape, average particle size, particle color, hardness, friability, toughness, density, specific surface area, and a combination thereof.

Item 62. The fixed abrasive article of item 61, wherein the second type of shaped abrasive particle comprises a second abrasive characteristic selected from the group consisting of two-dimensional shape, average particle size, particle color, hardness, friability, toughness, density, specific surface area, and a combination thereof.

Item 63. The fixed abrasive article of item 62, wherein at least one first abrasive characteristic and second abrasive characteristic are essentially the same compared to each other, wherein at least two first abrasive characteristics and two second abrasive characteristics are essentially the same compared to each other.

Item 64. The fixed abrasive article of item 62, wherein at least one first abrasive characteristic and one second abrasive characteristic are different compared to each other, wherein at least two first abrasive characteristics and two second abrasive characteristics are different compared to each other.

Item 65. The fixed abrasive article of item 1, wherein the second type of shaped abrasive particle comprises a body having a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height.

Item 66. The fixed abrasive article of item 65, wherein the height (h) is at least about 20% of the width (w) or at least about 25% or at least about 30% or at least about 33%, and not greater than about 80% or not greater than about 76% or not greater than about 73% or not greater than about 70% or not greater than about 68% of the width or not greater than about 56% of the width or not greater than about 48% of the width or not greater than about 40% of the width.

Item 67. The fixed abrasive article of item 65, wherein the height (h) is at least about 400 microns or at least about 450 microns or at least about 475 microns or at least about 500 microns, and not greater than about 3 mm or not greater than about 2 mm or not greater than about 1.5 mm or not greater than about 1 mm or not greater than about 800 microns.

Item 68. The fixed abrasive article of item 65, wherein the width is at least about 600 microns or at least about 700 microns or at least about 800 microns or at least about 900 microns, and not greater than about 4 mm or not greater than about 3 mm or not greater than about 2.5 mm or not greater than about 2 mm.

Item 69. The fixed abrasive article of item 65, wherein the body comprises a percent flashing of at least about 1%, such as at least about 2% or at least about 3% or at least about 5% or at least about 8% or at least about 10% or at least about 12% or at least about 15% or at least about 18% or at least about 20%, and not greater than about 40% or not greater than about 35% or not greater than about 30% or not greater than about 25% or not greater than about 20% or not greater than about 18% or not greater than about 15% or not greater than about 12% or not greater than about 10% or not greater than about 8% or not greater than about 6% or not greater than about 4%.

Item 70. The fixed abrasive article of item 65, wherein the body comprises a dishing value (d) of not greater than about 2 or not greater than about 1.9 or not greater than about 1.8 or not greater than about 1.7 or not greater than about 1.6 or not greater than about 1.5 or not greater than about 1.2, and at least about 0.9 or at least about 1.0.

Item 71. The fixed abrasive article of item 65, wherein the body comprises a primary aspect ratio of width:length of at least about 1:1 and not greater than about 10:1.

Item 72. The fixed abrasive article of item 65, wherein the body comprises a secondary aspect ratio defined by a ratio of width:height within a range between about 5:1 and about 1:1.

Item 73. The fixed abrasive article of item 65, wherein the body comprises a tertiary aspect ratio defined by a ratio of length:height within a range between about 6:1 and about 1:1.

Item 74. The fixed abrasive article of item 65, wherein the body comprises a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a shape selected from the group consisting of triangular, quadrilateral, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, and a combination thereof, wherein the body comprises a two-dimensional shape as viewed in a plane defined by a length and a width of the body selected from the group consisting of ellipsoids, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, complex polygonal shapes, irregular shapes, and a combination thereof.

Item 75. The fixed abrasive article of item 65, wherein the body comprises a two-dimensional triangular shape as viewed in a plane defined by a length and width.

Item 76. The fixed abrasive article of item 65, wherein the body is essentially free of a binder, wherein the body is essentially free of an organic material.

Item 77. The fixed abrasive article of item 65, wherein the body comprises a polycrystalline material, wherein the polycrystalline material comprises grains, wherein the grains are selected from the group of materials consisting of nitrides, oxides, carbides, borides, oxynitrides, diamond, and a combination thereof, wherein the grains comprise an oxide selected from the group of oxides consisting of aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof, wherein the grains comprise alumina, wherein the grains consist essentially of alumina.

Item 78. The fixed abrasive article of item 65, wherein the body consists essentially of alumina.

Item 79. The fixed abrasive article of item 65, wherein the body is formed from a seeded sol gel.

Item 80. The fixed abrasive article of item 65, wherein the body comprises a polycrystalline material having an average grain size not greater than about 1 micron.

Item 81. The fixed abrasive article of item 65, wherein the body is a composite comprising at least about two different types of grains.

Item 82. The fixed abrasive article of item 65, wherein the body comprises an additive, wherein the additive comprises an oxide, wherein the additive comprises a metal element, wherein the additive comprises a rare-earth element.

Item 83. The fixed abrasive article of item 82, wherein the additive comprises a dopant material, wherein the dopant material includes an element selected from the group consisting of an alkali element, an alkaline earth element, a rare earth element, a transition metal element, and a combination thereof, wherein the dopant material comprises an element selected from the group consisting of hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof.

Item 84. The fixed abrasive article of item 1, wherein the second type of shaped abrasive particle comprises a body having a first major surface, a second major surface, and at least one side surface extending between the first major surface and the second major surface.

Item 85. The fixed abrasive article of item 84, wherein the first major surface defines an area different than the second major surface, wherein the first major surface defines an area greater than an area defined by the second major surface, wherein the first major surface defines an area less than an area defined by the second major surface.

Item 86. A fixed abrasive article comprising:

a blend of abrasive particles comprising:

a first type of shaped abrasive particle comprising a first height (h**1**);

a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height; and

wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11 in^3.

Item 87. The fixed abrasive article of item 86, wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11.5 in^3 or at least about 12 in^3, and wherein the fixed abrasive article comprises a stainless steel lifespan of not greater than about 25 in^3.

Item 88. The fixed abrasive article of item 86, further comprising a height ratio (h**2**/h**1**) of not greater than about 0.98.

Item 89. The fixed abrasive article of item 88, wherein the height ratio (h**2**/h**1**) is at least about 0.05.

Item 90. The fixed abrasive article of item 86, further comprising a height difference (h**1**−h**2**) of at least about 1 micron.

Item 91. The fixed abrasive article of item 90, wherein the height difference (h**1**−h**2**) is not greater than about 2 mm.

Item 92. The fixed abrasive article of item 86, wherein the first type of shaped abrasive particle comprises a first length (l**1**), and the second type of shaped abrasive particle comprises a second length (l**2**), and further comprising a length ratio (l**1**/l**2**) of at least about 0.05.

Item 93. The fixed abrasive article of item 92, further comprising a length difference (L**1**−l**2**) of not greater than about 2 mm.

Item 94. The fixed abrasive article of item 86, wherein the first type of shaped abrasive particle comprises a first width (w**1**), and the second type of shaped abrasive particle comprises a second width (w**2**), and further comprising a width ratio (w**2**/w**1**) of at least about 0.05.

Item 95. The fixed abrasive article of item 94, further comprising a width difference (w**1**−w**2**) of not greater than about 2 mm.

Item 96. The fixed abrasive article of item 86, wherein the first content is less than the second content.

Item 97. The fixed abrasive article of item 86, wherein the first content is not greater than about 90% of a total content of the blend.

Item 98. The fixed abrasive article of item 86, wherein the first content is at least about 1% of a total content of the blend.

Item 99. The fixed abrasive article of item 86, wherein the second content is not greater than about 98% of a total content of the blend.

Item 100. The fixed abrasive article of item 86, wherein the second content is at least about 1% of a total content of the blend.

Item 101. The fixed abrasive article of item 86, wherein the blend of abrasive particles comprises a first content (C**1**) of the first type of shaped abrasive particle, and a second content (C**2**) of the second type of shaped abrasive particle, and further comprising a blend ratio (C**1**/C**2**) of not greater than about 10.

Item 102. The fixed abrasive article of item 86, wherein the blend of abrasive particles includes a majority content of shaped abrasive particles, wherein the blend of abrasive particles consists essentially of the first type of shaped abrasive particle and the second type of shaped abrasive particle.

Item 103. The fixed abrasive article of item 86, wherein the blend further comprises a third type of abrasive particle, wherein the third type of abrasive particle comprises a shaped abrasive particle, wherein the third type of abrasive particle comprises a diluent type of abrasive particle, wherein the diluent type of abrasive particle comprises an irregular shape.

Item 104. The fixed abrasive article of item 86, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

Item 105. The fixed abrasive article of item 86, wherein the fixed abrasive article comprises a substrate, wherein the substrate comprises a backing, wherein the backing comprises a woven material, wherein the backing comprises a non-woven material, wherein the backing comprises an organic material, wherein the backing comprises a polymer, wherein the backing comprises a material selected from the group consisting of cloth, paper, film, fabric, fleeced fabric, vulcanized fiber, woven material, non-woven material, webbing, polymer, resin, phenolic resin, phenolic-latex resin, epoxy resin, polyester resin, urea formaldehyde resin, polyester, polyurethane, polypropylene, polyimides, and a combination thereof.

Item 106. The fixed abrasive article of item 105, wherein the backing comprises an additive selected from the group consisting of catalysts, coupling agents, curants, anti-static agents, suspending agents, anti-loading agents, lubricants, wetting agents, dyes, fillers, viscosity modifiers, dispersants, defoamers, and grinding agents.

Item 107. The fixed abrasive article of item 105, further comprising an adhesive layer overlying the backing, wherein the adhesive layer comprises a make coat, wherein the make coat overlies the backing, wherein the make coat is bonded directly to a portion of the backing, wherein the make coat comprises an organic material, wherein the make coat comprises a polymeric material, wherein the make coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 108. The fixed abrasive article of item 107, wherein the adhesive layer comprises a size coat, wherein the size coat overlies a portion of the plurality of shaped abrasive particles, wherein the size coat overlies a make coat, wherein the size coat is bonded directly to a portion of the plurality of shaped abrasive particles, wherein the size coat comprises an organic material, wherein the size coat comprises a polymeric material, wherein the size coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 109. The fixed abrasive article of item 86, wherein the blend of abrasive particles comprises a plurality of shaped abrasive particles, and wherein each shaped abrasive particle of the plurality of shaped abrasive particles is arranged in a controlled orientation relative to a backing, the controlled orientation including at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation.

Item 110. The fixed abrasive article of item 86, wherein the first type of shaped abrasive particle comprises a body having a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height.

Item 111. The fixed abrasive article of item 110, wherein the height (h) is at least about 20% of the width (w), and not greater than about 80% of the width.

Item 112. The fixed abrasive article of item 110, wherein the body comprises a percent flashing of at least about 1%.

Item 113. The fixed abrasive article of item 110, wherein the body comprises a dishing value (d) of not greater than about 2.

Item 114. The fixed abrasive article of item 110, wherein the body comprises a primary aspect ratio of width:length of at least about 1:1 and not greater than about 10:1.

Item 115. The fixed abrasive article of item 110, wherein the body comprises a secondary aspect ratio defined by a ratio of width:height within a range between about 5:1 and about 1:1.

Item 116. The fixed abrasive article of item 110, wherein the body comprises a tertiary aspect ratio defined by a ratio of length:height within a range between about 6:1 and about 1:1.

Item 117. The fixed abrasive article of item 110, wherein the body comprises a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a shape selected from the group consisting of triangular, quadrilateral, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, and a combination thereof, wherein the body comprises a two-dimensional shape as viewed in a plane defined by a length and a width of the body selected from the group consisting of ellipsoids, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, complex polygonal shapes, irregular shapes, and a combination thereof.

Item 118. The fixed abrasive article of item 110, wherein the body is essentially free of a binder, wherein the body is essentially free of an organic material.

Item 119. The fixed abrasive article of item 110, wherein the body comprises a polycrystalline material, wherein the polycrystalline material comprises grains, wherein the grains are selected from the group of materials consisting of nitrides, oxides, carbides, borides, oxynitrides, diamond, and a combination thereof, wherein the grains comprise an oxide selected from the group of oxides consisting of aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof, wherein the grains comprise alumina, wherein the grains consist essentially of alumina.

Item 120. The fixed abrasive article of item 110, wherein the body comprises an additive, wherein the additive comprises an oxide, wherein the additive comprises a metal element, wherein the additive comprises a rare-earth element.

Item 121. The fixed abrasive article of item 86, wherein the first type of shaped abrasive particle comprises a first abrasive characteristic selected from the group consisting of two-dimensional shape, average particle size, particle color, hardness, friability, toughness, density, specific surface area, and a combination thereof.

Item 122. The fixed abrasive article of item 121, wherein the second type of shaped abrasive particle comprises a second abrasive characteristic selected from the group consisting of two-dimensional shape, average particle size, particle color, hardness, friability, toughness, density, specific surface area, and a combination thereof.

Item 123. The fixed abrasive article of item 122, wherein at least one first abrasive characteristic and second abrasive characteristic are essentially the same compared to each other, wherein at least two first abrasive characteristics and two second abrasive characteristics are essentially the same compared to each other.

Item 124. The fixed abrasive article of item 122, wherein at least one first abrasive characteristic and one second abrasive characteristic are different compared to each other, wherein at least two first abrasive characteristics and two second abrasive characteristics are different compared to each other.

Item 125. The fixed abrasive article of item 110, wherein the second type of shaped abrasive particle comprises a body having a length (l), a width (w), and a height (hi), wherein the width>length, the length>height, and the width>height.

Item 126. The fixed abrasive article of item 125, wherein the height (h) is at least about 20% of the width (w), and not greater than about 80% of the width.

Item 127. The fixed abrasive article of item 125, wherein the height (h) is at least about 400 microns.

Item 128. The fixed abrasive article of item 125, wherein the width is at least about 600 microns.

Item 129. The fixed abrasive article of item 125, wherein the body comprises a percent flashing of at least about 1%.

Item 130. The fixed abrasive article of item 125, wherein the body comprises a dishing value (d) of not greater than about 2.

Item 131. The fixed abrasive article of item 125, wherein the body comprises a primary aspect ratio of width:length of at least about 1:1 and not greater than about 10:1.

Item 132. The fixed abrasive article of item 125, wherein the body comprises a secondary aspect ratio defined by a ratio of width:height within a range between about 5:1 and about 1:1.

Item 133. The fixed abrasive article of item 125, wherein the body comprises a tertiary aspect ratio defined by a ratio of length:height within a range between about 6:1 and about 1:1.

Item 134. The fixed abrasive article of item 125, wherein the body comprises a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a shape selected from the group consisting of triangular, quadrilateral, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, and a combination thereof, wherein the body comprises a two-dimensional shape as viewed in a plane defined by a length and a width of the body selected from the group consisting of ellipsoids, Greek alphabet characters, Latin alphabet characters, Russian alphabet characters, complex polygonal shapes, irregular shapes, and a combination thereof.

Item 135. The fixed abrasive article of item 125, wherein the body comprises a two-dimensional triangular shape as viewed in a plane defined by a length and width.

Item 136. The fixed abrasive article of item 125, wherein the body is essentially free of a binder, wherein the body is essentially free of an organic material.

Item 137. The fixed abrasive article of item 125, wherein the body comprises a polycrystalline material, wherein the polycrystalline material comprises grains, wherein the grains are selected from the group of materials consisting of nitrides, oxides, carbides, borides, oxynitrides, diamond, and a combination thereof, wherein the grains comprise an oxide selected from the group of oxides consisting of aluminum oxide, zirconium oxide, titanium oxide, yttrium oxide, chromium oxide, strontium oxide, silicon oxide, and a combination thereof, wherein the grains comprise alumina, wherein the grains consist essentially of alumina.

Item 138. The fixed abrasive article of item 125, wherein the body is a composite comprising at least about 2 different types of abrasive grains.

Item 139. The fixed abrasive article of item 125, wherein the body comprises an additive, wherein the additive comprises an oxide, wherein the additive comprises a metal element, wherein the additive comprises a rare-earth element.

Item 140. The fixed abrasive article of item 125, wherein the additive comprises a dopant material, wherein the dopant material includes an element selected from the group consisting of an alkali element, an alkaline earth element, a rare earth element, a transition metal element, and a combination thereof, wherein the dopant material comprises an element selected from the group consisting of hafnium, zirconium, niobium, tantalum, molybdenum, vanadium, lithium, sodium, potassium, magnesium, calcium, strontium, barium, scandium, yttrium, lanthanum, cesium, praseodymium, chromium, cobalt, iron, germanium, manganese, nickel, titanium, zinc, and a combination thereof.

Item 141. A method of removing material from a workpiece using an abrasive article including a blend of abrasive particles comprising:

a first type of shaped abrasive particle comprising a first height (h1);

a second type of shaped abrasive particle comprising a second height (h2) less than the first height.

Item 142. The method of item 141, wherein the workpiece comprises a material selected from the group consisting of an organic material, an inorganic material, and a combination thereof, wherein the workpiece comprises a metal, wherein the workpiece comprises a metal alloy.

Item 143. The method of item 141, wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11 in^3.

Item 144. The method of item 141, further comprising a height ratio (h2/h1) of not greater than about 0.98.

Item 145. The method of item 144, wherein the height ratio (h2/h1) is at least about 0.05.

Item 146. The method of item 141, further comprising a height difference (h1−h2) of at least about 1 micron.

Item 147. The method of item 146, wherein the height difference (h1−h2) is not greater than about 2 mm.

Item 148. The method of item 141, wherein the first type of shaped abrasive particle comprises a first length (l1), and the second type of shaped abrasive particle comprises a second length (l2), and further comprising a length ratio (l1/l2) of at least about 0.05.

Item 149. The method of item 148, further comprising a length difference (L1−l2) of not greater than about 2 mm.

Item 150. The method of item 141, wherein the first type of shaped abrasive particle comprises a first width (w1), and the second type of shaped abrasive particle comprises a second width (w2), and further comprising a width ratio (w2/w1) of at least about 0.05.

Item 151. The method of item 150, further comprising a width difference (w1−w2) of not greater than about 2 mm.

Item 152. The method of item 141, wherein the blend of abrasive particles comprises a first content (C1) of the first type of shaped abrasive particle, and a second content (C2) of the second type of shaped abrasive particle, and further comprising a blend ratio (C1/C2) of not greater than about 10.

Item 153. The method of item 141, wherein the blend of abrasive particles includes a majority content of shaped abrasive particles, wherein the blend of abrasive particles consists essentially of the first type of shaped abrasive particle and the second type of shaped abrasive particle.

Item 154. The method of item 141, wherein the blend further comprises a third type of abrasive particle, wherein the third type of abrasive particle comprises a shaped abrasive particle, wherein the third type of abrasive particle comprises a diluent type of abrasive particle, wherein the diluent type of abrasive particle comprises an irregular shape.

Item 155. The method of item 141, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

Item 156. The method of item 141, wherein the fixed abrasive article comprises a substrate, wherein the substrate comprises a backing, wherein the backing comprises a woven material, wherein the backing comprises a non-woven material, wherein the backing comprises an organic material, wherein the backing comprises a polymer, wherein the backing comprises a material selected from the group consisting of cloth, paper, film, fabric, fleeced fabric, vulcanized fiber, woven material, non-woven material, webbing, polymer, resin, phenolic resin, phenolic-latex resin, epoxy resin, polyester resin, urea formaldehyde resin, polyester, polyurethane, polypropylene, polyimides, and a combination thereof.

Item 157. The method of item 156, wherein the backing comprises an additive selected from the group consisting of catalysts, coupling agents, curants, anti-static agents, suspending agents, anti-loading agents, lubricants, wetting agents, dyes, fillers, viscosity modifiers, dispersants, defoamers, and grinding agents.

Item 158. The method of item 157, wherein further comprising an adhesive layer overlying the backing, wherein the adhesive layer comprises a make coat, wherein the make coat overlies the backing, wherein the make coat is bonded directly to a portion of the backing, wherein the make coat comprises an organic material, wherein the make coat comprises a polymeric material, wherein the make coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, poly vinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 159. The method of item 158, wherein the adhesive layer comprises a size coat, wherein the size coat overlies a portion of the plurality of shaped abrasive particles, wherein the size coat overlies a make coat, wherein the size coat is bonded directly to a portion of the plurality of shaped abrasive particles, wherein the size coat comprises an organic material, wherein the size coat comprises a polymeric material, wherein the size coat comprises a material selected from the group consisting of polyesters, epoxy resins, polyurethanes, polyamides, polyacrylates, polymethacrylates, polyvinyl chlorides, polyethylene, polysiloxane, silicones, cellulose acetates, nitrocellulose, natural rubber, starch, shellac, and a combination thereof.

Item 160. The method of item 141, wherein the blend of abrasive particles comprises a plurality of shaped abrasive particles, and wherein each shaped abrasive particle of the plurality of shaped abrasive particles is arranged in a controlled orientation relative to a backing, the controlled orientation including at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation.

EXAMPLES

Example 1

Five samples were used to conduct a comparative grinding operation. Each of the five samples used essentially the same structure including backing and adhesive layers, however the samples differed in the type of abrasive particles. A first sample, Sample **S1**, represents a coated abrasive including a blend of shaped abrasive particles according to embodiments described herein. Sample **S1** includes a plurality of a first type of shaped abrasive particles having a median internal height of approximately 500 microns. The blend further includes a plurality of a second type of shaped abrasive particles having a median internal height of approximately 400 microns. The blend has a ratio (C**1**/C**2**) of approximately 2.3. Approximately 80% of the shaped abrasive particles of the blend are positioned in a predetermined side orientation on the backing and have a normalized weight of shaped abrasive particles of 40 lbs./ream.

A second sample, Sample S**2**, represents a coated abrasive including a blend of shaped abrasive particles according to embodiments described herein. Sample S**2** includes a plurality of a first type of shaped abrasive particles having a median internal height of approximately 500 microns. The blend further includes a plurality of a second type of shaped abrasive particles having a median internal height of approximately 400 microns. The blend has a ratio (C**1**/C**2**) of approximately 1. Approximately 80% of the shaped abrasive particles of the blend are positioned in a predetermined side orientation on the backing and have a normalized weight of shaped abrasive particles of 40 lbs./ream.

A third sample, Sample S**3**, represents a coated abrasive including a blend of shaped abrasive particles according to embodiments described herein. Sample S**3** includes a plurality of a first type of shaped abrasive particles having a median internal height of approximately 500 microns. The blend further includes a plurality of a second type of shaped abrasive particles having a median internal height of approximately 400 microns. The blend has a ratio (C**1**/C**2**) of approximately 0.43. Approximately 80% of the shaped abrasive particles of the blend are positioned in a predetermined side orientation on the backing and have a normalized weight of shaped abrasive particles of 40 lbs./ream.

A fourth sample, Sample CS**4** represents a conventional coated abrasive article including a single type of shaped abrasive particle having a median internal height of approximately 400 microns. Approximately 80% of these shaped abrasive particles are positioned in a predetermined side orientation on the backing and have a normalized weight of shaped abrasive particles of 40 lbs./ream.

A fifth sample, Sample CS**5**, represents a conventional coated abrasive article including a single type of shaped abrasive particle having a median internal height of approximately 500 microns. Approximately 80% of these shaped abrasive particles are positioned in a predetermined side orientation on the backing and have a normalized weight of shaped abrasive particles of 40 lbs./ream.

The samples were tested in an automated grinding system according to the conditions provided in Table 1 below.

TABLE 1

Test platform:	Okuma Screening Test
Test conditions:	Dry, Straight Plunge
	Constant MRR' = 4 inch^3/min/inch
	Belt speed = Vs = 7500 sfpm (38 m/s)

TABLE 1-continued

	Work material: 304L ss
	Hardness: 104 HRB
	Size: 0.5"×0.5" × 6 inches
	Contact width = 0.5" inch
Measurements:	Power, Grinding Forces, MRR' and SGE

FIG. **11** includes a plot of specific grinding energy versus cumulative material removed for each of the samples. As clearly illustrated, the life of Sample CS**5** was significantly less than Samples S**2** and S**3**. Quite remarkably, and unexpectedly, and despite Samples S**2**-S**3** having a blend of a first type of shaped abrasive particle and a second type of shaped abrasive particle, which may be expected to have a cumulative material removal rate that is between Samples CS**4** and CS**5**, Samples S**2** and S**3** had a life that was equivalent to CS**4** and greater than CS**5**. Moreover, each of the Samples S**1**-S**3** had an initial specific grinding energy between 0 to 5 cubic inches of material removed that was lower than the comparative samples CS**4** and CS**5** in the same initial stages. Moreover, and equally unexpected, Sample S**3** has a lower specific grinding energy for the majority of the test as compared to either Sample CS**1** or Sample CS**2**.

The present application represents a departure from the state of the art. The coated abrasive articles of the embodiments herein include a particular combination of features distinct from other conventionally available abrasive articles including, but not limited to, incorporation of a blend including a first type of shaped abrasive particle and a second type of shaped abrasive particle. Notably, the first type and second type of shaped abrasive particles can have a particular combination of features including, but not limited to, a difference in height with respect to each other. Moreover, each of the shaped abrasive particles can have particular features, such as aspect ratio, composition, additives, two-dimensional shape, three-dimensional shape, intern height, difference in height profile, flashing percentage, dishing, and the like. Moreover, the blend may utilize a combination of certain features including, but not limited to, height ratio, height difference, length ratio, length difference, width ratio, width difference, relative contents of the first and second types of shaped abrasive particles, and the like. Moreover, while not completely understood and without wishing to be tied to a particular theory, it is thought that one or a combination of these features of the embodiments described herein facilitate the remarkable and unexpected performance of these coated abrasive articles.

Certain features, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

The specification and illustrations of the embodiments described herein are intended to provide a general understanding of the structure of the various embodiments. The specification and illustrations are not intended to serve as an exhaustive and comprehensive description of all of the elements and features of apparatus and systems that use the structures or methods described herein. Separate embodiments may also be provided in combination in a single embodiment, and conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, reference to values stated in ranges includes each and every value within that range. Many other embodiments may be apparent to skilled artisans only after reading this specification. Other embodiments may be used and derived from the disclosure, such that a structural substitution, logical substitution, or another change may be made without departing from the scope of the disclosure. Accordingly, the disclosure is to be regarded as illustrative rather than restrictive.

The following description in combination with the figures is provided to assist in understanding the teachings disclosed herein. The following discussion will focus on specific implementations and embodiments of the teachings. This focus is provided to assist in describing the teachings and should not be interpreted as a limitation on the scope or applicability of the teachings. However, other teachings can certainly be used in this application.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or inherent to such method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

Also, the use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural, or vice versa, unless it is clear that it is meant otherwise. For example, when a single item is described herein, more than one item may be used in place of a single item. Similarly, where more than one item is described herein, a single item may be substituted for that more than one item.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples are illustrative only and not intended to be limiting. To the extent not described herein, many details regarding specific materials and processing acts are conventional and may be found in reference books and other sources within the structural arts and corresponding manufacturing arts.

The above-disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments, which fall within the true scope of the present invention. Thus, to the maximum extent allowed by law, the scope of the present invention is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

The Abstract of the Disclosure is provided to comply with Patent Law and is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description of the Drawings, various features may be grouped together or described in a single embodiment for the purpose of streamlining the disclosure. This disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may be directed to less than all features of any of the disclosed embodiments. Thus, the following claims are incorporated into the Detailed Description of the Drawings, with each claim standing on its own as defining separately claimed subject matter.

What is claimed is:

1. A fixed abrasive article comprising:

a blend of abrasive particles comprising:

a first content (C**1**) of a first type of shaped abrasive particle comprising a first height (h**1**);

a second content (C**2**) of a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height, and

a height ratio (h**2**/h**1**) of at least about 0.2 and not greater than about 0.98,

wherein the first content is at least about 1% and not greater than about 70% of the total content of the blend, and

wherein the second content at least about 1% and not greater than about 98% of the total content of the blend.

2. The fixed abrasive article of claim **1**, wherein the height ratio (h**2**/h**1**) is at least 0.5 and not greater than 0.9.

3. The fixed abrasive article of claim **1**, further comprising a height difference (h**1**−h**2**) of at least about 1 micron and not greater than about 2 mm.

4. The fixed abrasive article of claim **1**, wherein the first type of shaped abrasive particle comprises a first length (l**1**), and the second type of shaped abrasive particle comprises a second length (l**2**), and further comprising a length ratio (l**1**/l**2**) of at least about 0.05 and not greater than about 10.

5. The fixed abrasive article of claim **1**, wherein the first content is at least about 10% and not greater than about 50% of the total content of the blend, and wherein the second content at least about 20% and not greater than about 90% of the total content of the blend.

6. The fixed abrasive article of claim **1**, wherein the first content is at least about 25% and not greater than about 35% of the total content of the blend, and wherein the second content at least about 50% and not greater than about 75% of the total content of the blend.

7. The fixed abrasive article of claim **1**, further comprising a blend ratio (C**1**/C**2**) of at least about 0.1 and not greater than about 10.

8. The fixed abrasive article of claim **7**, wherein the blend ratio (C**1**/C**2**) is at least about 0.1 and not greater than about 2.5.

9. The fixed abrasive article of claim **1**, wherein the blend further comprises a third type of abrasive particle including a shaped abrasive particle.

10. The fixed abrasive article of claim **1**, wherein the fixed abrasive article is selected from the group consisting of a bonded abrasive article, a coated abrasive article, and a combination thereof.

11. The fixed abrasive article of claim **1**, wherein the blend of abrasive particles comprises a plurality of shaped abrasive particles, and wherein each shaped abrasive particle of the plurality of shaped abrasive particles is arranged in a controlled orientation relative to a backing, the controlled orientation including at least one of a predetermined rotational orientation, a predetermined lateral orientation, and a predetermined longitudinal orientation.

12. The fixed abrasive article of claim **11**, wherein a majority of the first type of abrasive particles are coupled to the backing in a side orientation and wherein a majority of the second type of abrasive particles are coupled to the backing in a side orientation.

13. The fixed abrasive article of claim **1**, wherein the first type of shaped abrasive particle comprises a body having a length (l), a width (w), and a height (hi), wherein the width≥length, the length≥height, and the width≥height, and wherein the body comprises a two-dimensional polygonal shape as viewed in a plane defined by a length and width, wherein the body comprises a shape selected from the group consisting of triangular, quadrilateral, rectangular, trapezoidal, pentagonal, hexagonal, heptagonal, octagonal, and a combination thereof.

14. The fixed abrasive article of claim **13**, wherein the body comprises a polycrystalline material selected from the group of materials consisting of nitrides, oxides, carbides, borides, oxynitrides, diamond, and a combination thereof.

15. The fixed abrasive article of claim **1**, wherein the fixed abrasive article comprises a stainless steel lifespan of at least about 11 in^3 and not greater than about 25 in^3.

16. A fixed abrasive article comprising:

a blend of abrasive particles comprising:

- a first content (C**1**) of a first type of shaped abrasive particle comprising a first height (h**1**);
- a second content (C**2**) of a second type of shaped abrasive particle comprising a second height (h**2**) less than the first height,
- a height ratio (h**2**/h**1**) of at least about 0.2 and not greater than about 0.98, and
- a blend ratio (C**1**/C**2**) is at least about 0.1 and not greater than about 2.5.

17. The fixed abrasive of claim **16**, wherein the height ratio is at least about 0.5 and not greater than about 0.9.

18. The fixed abrasive of claim **16**, wherein the first content is at least 10% the total content of the blend, and wherein the second content at least 20% of the total content of the blend.

19. The fixed abrasive of claim **16**, wherein the blend further comprises a third content comprising a third type of shaped abrasive particle.

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